Norwegian College of Fishery Science | Faculty of Bioscience, Fisheries and Economics

Snow crab (*Chionoecetes opilio*) interactions with bottom trawls and possible conflicts between trawl fleets and pot fisheries in the Northeast Barents Sea

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Allison Luettel

Abstract

Approximately two decades ago, snow crab (*Chionoecetes opilio*) were discovered in the Barents Sea. The areas in which they have come to establish themselves, in many instances, overlaps with areas trawled by the commercial groundfish fleet, consequently, leading to interactions between snow crab and bottom gear. Snow crabs, which after settling to the bottom go through a series of molts in order to reach maturity. During this period, they are particularly vulnerable, especially in an area like the Barents Sea, which has a year round bottom fishery.

The aim of this study is to look at the interactions taking place between *C. opilio* and the groundrope used in the traditional commercial fleet, by conducting direct *in situ* video observations of the encounters to examine the crab's behaviour. In addition to behaviour, snow crab injuries were recorded in order to determine, what, if any factors might influence injury(s) sustained during interaction with the mobile gear. This experiment employed a modified two-panel version of an Alfredo No. 3 trawl with a retainer bag affixed underneath the center section of the gear to sample snow crabs that escaped below the central section of the trawl.

Keywords: snow crab, *Chionoecetes opilio*, Barents Sea, video, behavior, injury

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Acronyms

Acronyms	
ADF&G	Alaska Department of Fish and Game
CDQ	Community Development Quota
CW	Carapace Width
DFO	Fisheries and Oceans Canada
FRCC	Fisheries Resource Conservation Council
IFQ	Individual Fishing Quota
IMR	Institute of Marine Research
NEZ	Norwegian Economic Zone
NOAA	National Oceanic and Atmospheric Administration
PA	Polyamide
PE	Polyethylene
PINRO	Knipovich Polar Research Institute of Marine Fisheries and Oceanography
RAMP	Reflex Action Mortality Predictor
REZ	Russian Economic Zone
SCSG	Semi-circular spreading gear
TAC	Total Allowable Catch
VMS	Vessel Monitoring System

1.0 Introduction

Approximately two decades ago, snow crab (*Chionoecetes opilio*) were discovered in the Barents Sea. The areas in which they have come to establish themselves, in many instances, overlaps with areas trawled by the commercial groundfish fleet, consequently, leading to interactions between snow crab and bottom gear. Snow crabs, which after settling to the bottom go through a series of molts in order to reach maturity. During this period, they are particularly vulnerable, especially in an area that has a year round bottom fishery.

1.1 Distribution

Snow crab (*Chionoecetes opilio*) are naturally distributed in multiple areas in the oceans of the northern hemisphere. In the northwestern Atlantic, snow crab are found mainly in the near-shore waters surrounding western Greenland and down through Newfoundland and Labrador, Canada and extending all the way to the Gulf of Maine in the United States. The species is also indigenous to the North Pacific where the distribution ranges broadly from Alaska in the United States, throughout the Bering Sea to Eastern Russia and down to Japan and Korea. Snow crabs also inhabit the Arctic Ocean, from Cape Perry in Canada's Northwest Territories, the Beaufort Sea, the shelf of the Laptev Sea and the Eastern Siberian Sea (Figure 1) (Alvsvåg et al., 2009, Jadamec et al., 1999).

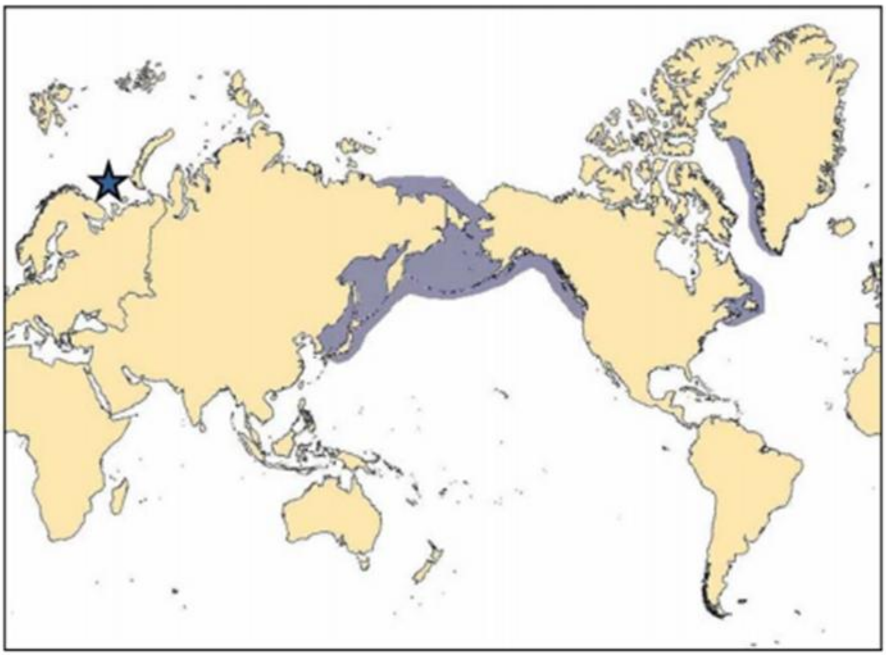

Figure 1. Natural distribution range of snow crab (*Chionoecetes opilio*). Star indicates the observations of a new population in the northeast Atlantic (Alvsvåg et al., 2009).

To date there had been no observations of snow crabs in the Eastern Atlantic; however, in 1996 there was reported capture of five individuals in the southeastern part of the Barents Sea by Russian commercial fishing vessels (marked by the star in Fig 1) (Agnalt et al., 2011, Kuzmin et al., 1999). Russian fishers captured the first two crabs in the Norwegian part of the Barents Sea in 2001 and in the spring of 2003, for the first time, Norwegian fishers caught two snow crabs in coastal waters off Finnmark (Alvsvåg et al., 2009, Agnalt et al., 2011, Dvoretsky and Dvoretsky, 2015). Since then, snow crab has routinely been caught as a bycatch both in the coastal gillnet fishery and during scientific and commercial trawling in the central and northern Barents Sea (Pavlov and Sundet, 2011).

In their joint annual ecosystem bottom-trawl survey, Norway's *Institute of Marine Research* (IMR) and Russia's *Knipovich Polar Research Institute of Marine Fisheries and Oceanography* (PINRO) paid special attention from February 2004-2006 to include recordings of snow crabs in order to evaluate if the introduced species had succeeded in becoming an established self-sustaining species in the region (Alvsvåg et al., 2009). The results of the survey confirmed previous Russian observations of snow crab in the northern region of Gåsebanken (Goose Bank) as well as in the central region of the Barents Sea. The results of the recently conducted Joint Russian-Norwegian ecosystem surveys have shown a tendency for an increase in the total number of snow crabs, with majority of the population being observed in the Russian Economic Zone (REZ) of the Barents Sea (Dvoretsky and Dvoretsky, 2015). Since 2006, the quantity of crab bycatch in the northeastern and southeastern Barents Sea has increased. This combined with an increased aggregation of small crabs, led Dvoretsky and Dvoretsky (2015) to postulate the area to be a favorable nursery grounds for snow crabs. In addition, a significant number of *C. opilio* crab have been captured in the central Barents Sea. While a Russian snow crab fishery has not yet been implemented[1], from December 2012 to mid-2013, a Norwegian vessel caught approximately 100 tonnes of snow crab in international waters of the Barents Sea. In May 2013, one Spanish vessel joined this fishery and its catch of snow crabs exceeded 100 tonnes by July 2013 (Dvoretsky and Dvoretsky, 2015, Goryanina et al., 2013).

[1] According to Anonymous (2014b), the Ministry of Agriculture of the Russian Federation proposed the following measures for the 2015 snow crab fishery in the North Basin of the Barents Sea: a TAC of 1,100 tonnes, a minimum size limit of 100 m, and a gear restricted to traps. A search of the Ministry of Agriculture of the Russian Federation website http://www.mcx.ru/ yielded no results for confirming this information

In conjunction with the noted expansion, Snow crabs occur mainly in the eastern Barents Sea, however single animals have now been recorded in the western and northern parts of the Sea (Agnalt et al., 2011, Pavlov and Sundet, 2011). In the new, non-indigenous area, the known range of the snow crab is between 69°N and 79°N and 27°E to 56°E (Dvoretsky and Dvoretsky, 2015). However, in 2008, three male crabs were captured in the southern Saint Anna Trough (north of Novaya Zemlya, Russia) at the entrance to the Kara Sea (Agnalt et al., 2011). In 2009, a single male crab was caught in the northeastern Barents Sea (79°03'N 51°10'E) by a Russian research vessel during an ecosystem survey (Pavlov and Sundet, 2011). And in October 2012, an expedition aboard the R/V *Dalnie Zelentsy* found four male *C. opilio* in trawl catches in the southwestern Kara Sea (Zimina, 2014).

It is still not clear how snow crab came to be in the Barents Sea. There are indications that snow crab were observed during a mid-1800s French expedition, however, it is not known whether the explorers were in the Barents Sea or closer to Greenland, or if they correctly identified the species. More plausible theories on their immigration include dispersal via ballast water, larval advection by ocean currents and migration across the ocean floor. To help determine this, DNA extracted from *C. opilio* samples collected in 2004 in the Barents Sea at IMR in Bergen were sent for preliminary testing of microsatellite variations. These samples did not cluster with samples from the West Atlantic, and gave rise to the possibility of a genetic relationship with snow crab of the north Pacific. Samples obtained during a more recent investigation in the Barents Sea (Alvsvåg et al., 2009) were again sent to the same laboratory for microsatellite analyses. The mtDNA analysis indicated a linkage with Canadian populations (Sévigny and Sainte-Marie, 2009). Despite this work, the origin of the snow crab population in the Barents Sea remains unclear and needs to be investigated further (Agnalt et al., 2011). During a research workshop on king and snow crabs in the Barents Sea (Tromsø, Norway in 2014) Jan H. Sundet, IMR, questioned whether the crab have migrated westwards from a native population in the Chukchi Sea, north of the Bering Strait; he indicated that catches of the snow crab both in the East Siberian Sea and in the Laptev Sea could strengthen such a hypothesis (Hjelset, 2014).

1.2 Biology

The snow crab was first classified by Otto Fabricius in 1788, and the World Register of Marine Species has the following taxonomic classification registered (Davie, 2015):

Kingdom: Animalia
Phylum: Arthropoda
Subphylum: Crustacea
Class: Malacostraca
Order: Decapoda
Infraorder: Brachyura
Superfamily: Majoidea
Family: Oregoniidae
Genus: *Chionoecetes*
Species: *C. opilio*

Snow crabs are a subarctic species and the adults are usually found at depths from 0 to 450 m, and temperatures from 0 to 5°C (Tremblay, 1997). In the Barents Sea they have been found to inhabit bottom water above and below zero degrees Celsius, with a range from -0.7 to 3.4°C (Alvsvåg et al., 2009). First time spawners mate and lay eggs in late winter to early spring (December to April) and from April to June for repeat-spawners. Diet is dependent on life stages, with larvae feeding primarily on plankton whereas; juveniles and adults are opportunistic omnivores and will eat almost anything biological. Major components of their diet include bivalves, polychaete worms, gastropods, crabs (including other snow crabs) and fish. In turn, they are consumed by a wide variety of predators including ground fish, cod, flatfishes, skates and seals.

1.2.1 Life Stages

A snow crab's life cycle has been listed as lasting anywhere from 12 years (NOAA, 2015b) up to 19 years for adult large-claw males (Comeau et al., 1998). The spawning and hatching period[2] in the northwestern Atlantic takes place between April and June, depending on temperature (Robichaud et al., 1989, Webb et al., 2007). In the Eastern Bering Sea, Kruse et al. (2007) suggest the presence of senescent phytoplankton provide a chemical cue that allows

[2] Timing of the life stages can vary within the season from location to location based on environmental conditions. While detailed information on some of the areas snow crab occur will be included in this section, it should be treated as a general guideline of when these events are likely occurring.

larval hatching (see Table 1, stage 7) to be timed with a post plankton-bloom period when diatoms and copepod nauplii are likely to be present as prey for crab larvae, inferably improving larval survival. In addition, the timing of the sea ice melt in early spring plays an important role for generating stratification as colder temperatures may lengthen or delay the hatching period (Kruse et al., 2007, Stabeno et al., 1998).

Table 1. Stages of a snow crab life cycle involving reproduction (stages 1-6) and survival (stages 7-15) (Kruse et al., 2007).

Stage	**Description**
1	Ovary development and potential fecundity for prepubescent, pubescent and primiparous females
2	Ovary development and potential fecundity for multiparous females
3	Mating, egg fertilization and realized fecundity for primiparous females
4	Mating, egg fertilization and realized fecundity for multiparous females
5	Brooding of embryos for primiparous females
6	Brooding of embryos for multiparous females
7	Hatching of embryos
8	Zoeal larvae (two stages – zoea I and zoea II)
9	Megalops larvae
10	First-year benthic juveniles (3 instars, age 0)
11	Later juveniles of ages 1 to 4 years
12	Adolescent males (ages 5 to 10 years) and prepubescent females (ages 3 to 7)
13	Adult (large-claw) males with new shells (sublegal and legal size), ages 5 to 11 years
14	Adult (large-claw) males with old shells, up to maximum ages 11 to 17 years (i.e., up to 6 years post-molt to maturity)
15	Adult (large abdomen) females, up to maximum age 10 to 13 years (i.e., up to 6 years post-molt to maturity)

The two zoeal stages (Table 1, stage 8) occur in the upper mixed layer over intermediate depth areas (Kruse et al., 2007). In the Bering Sea, snow crab zoea are abundant from April to June (Incze et al., 1987). After hatching in June in the southern Gulf of St. Lawrence, Atlantic Canada (Moriyasu and Lanteigne, 1998) and during May and June in Bonne Bay, Newfoundland (Comeau et al., 1999), zoea remain in the water column until settling anywhere between August to October (Lovrich et al., 1995). Duration of both zoeal larval stages vary inversely related to temperature and also on food availability (Kon, 1970).

Megalops larvae (Table 1, stage 9) appear in the water column at the end of July in the southern Gulf of St. Lawrence and during August with settlement in October in the northern Gulf of St. Lawrence and Newfoundland where they metamorphose into juveniles (Lovrich et al., 1995).

The pelagic stages of snow crab last approximately 3 – 5 months, Comeau et al. (1998) infers that megalopae settle and molt to instar I (ca. 3.0 mm cw Tables 2 and 3) during September or October in Bonne Bay, Newfoundland.

Table 2. Mean size (SD in parenthesis), age, percent size increment, and duration of instars of female and male snow crabs estimated from model analysis of size-frequency distributions Macdonald and Pitcher (1979) of individuals captured from 1988 to 1993 in Bonne Bay (Comeau et al., 1998).

(A) Females

Instar	Age (years)	Mean size (mm CW)	Immature % increment	Duration (years)	Mean size (mm CW)	Mature % increment	Duration (years)
I	0^{+}						
II	1						
III	1^{+}						
IV	2	9.7 (0.72)		<1 (±6 months)			
V	2^{+}	14.7 (1.05)	52	<1 (±6 months)			
VI	3	20.9 (1.77)	42	1			
VII	4	27.7 (1.87)	36	1			
VIII	5	36.2 (3.24)	31	1			
IX	6	46.4 (4.60)	28	1			
X	7	54.4 (4.63)	17	1	54.9 (3.96)	18	±5
XI	8				65.4 (4.10)	20	±5

(B) Males

Instar	Age (years)	Mean size (mm CW)	Immature % increment	Duration (years)	Mean size (mm CW)	Juvenile % increment	Duration (years)
I	0^{+}	3.1 (0.25)		<1 (±6 months)			
II	1	5.0 (0.51)	63	<1 (±6 months)			
III	1^{+}	7.0 (0.52)	41	<1 (±6 months)			
IV	2	9.8 (0.76)	39	<1 (±6 months)			
V	2^{+}	14.9 (1.32)	52	<1 (±6 months)			
VI	3	21.6 (1.63)	50	1			
VII	4	28.0 (1.99)	30	1			
VIII	5				38.3 (5.00)	37	1
IX	6				50.2 (2.52)	31	1
X	7				65.0 (6.48)	29	1–2[a]
XI	8				78.6 (7.28)	21	1–2[a]
XII	9				94.4 (6.51)	20	1–2[a]
XIII	10				112.0	19	1–2[a]
XIV	11						

(C) Mature males

Instar	Age (years)	Mean size (mm CW)	Mature % increment	Duration (years)
I	0^{+}			
II	1			
III	1^{+}			
IV	2			
V	2^{+}			
VI	3			
VII	4			
VIII	5			
IX	6			
X	7			
XI	8	73.4 (7.49)	13	±5
XII	9	99.5 (6.70)	27	±5
XIII	10	116.2 (6.28)	23	±5
XIV	11	131.4	17	±5

Note: Mean size of instars I to VI were determined from the Devismes trawl and the Icelandic scallop dredge surveys, and the mean size of instars VII to XIII were determined from the Nephrops trawl surveys. Missing average sizes of juvenile males (instar XII) and mature males (instar XIII) were extrapolated using the Hiatt (1948) growth equation. Percentage is of carapace increment per molt compared with postmolt CW.

[a]Larger juvenile males may skip a molt, increasing the intermolt period to 2 years.

Table 3. A Comparison of the mean size of snow crab instars found by Ito (1970) and Kon (1980) in the Sea of Japan, Robichaud et al. (1989) in the southwestern Gulf of St. Lawrence, Sainte-Marie et al. (1995) in the northwestern Gulf of St. Lawrence, and "this study" in Bonne Bay, Newfoundland as conducted by Comeau et al. (1998).

	Ito (1970)		Kon (1980)		Robichaud et al. (1989)		Sainte-Marie et al. (1995)	This study				
								Female		Male		
Instar	Female	Male	Female	Male	Female	Male	Male	Immature	Mature	Immature	Juvenile	Mature
I	2.9–3.0		3.1		2.8		3.19			3.1		
II	4.3–4.4		4.6		4.5		5.12			5.0		
III	6.0–7.0		6.5		6.8		7.65			7.0		
IV	9–10		9.7		9.9		10.97	9.7		9.8		
V	13–14		13.5		13.9		15.32	14.7		14.9		
VI	19–20		19.0	19.6	19.7	19.5	21.02	20.9		21.6		
VII	27–28		27.9	27.3	27.1	26.9	28.48	27.7		28.0		
VIII	37–38		37.2	36.8	37.0	36.9	38.25	36.2			38.3	
IX	49–50		49.6	49.2	50.6	50.3	50.73	46.4			50.2	
X	65–66	63–64	66.2	65.2	68.7	68.3	64.53	54.4	54.9		65.0	
XI	75–76	81–82	77.4	80.0			79.79		65.4		78.6	73.4
XII	83–86	97–98		93.4			96.67				94.4	99.5
XIII		111–112		105.6			115.34				112.0	116.2
XIV		121–122		116.7			135.99					131.4
XV		131–132		126.8								
XVI		137–138		135.9								
XVII				144.2								

Once settled to the bottom snow crabs exhibit rapid growth, molting approximately twice per year (Tables 4) (Comeau et al., 1998, Sainte-Marie et al., 1995). Around May, approximately 1 year after hatching, the absence of instar I and the presence of instar II (ca. 5.0 mm cw) suggests a molt during the winter months of the first settling stage (Table 1, stages 10 and 11). Based on laboratory observations, Watson (1969) suggested that instars I – VII go through an ecdysis every 6 months, field data collected by Comeau et al. (1998) confirms a 6-month intermolt for instars I – V, but not for instars VI – VII which have a 1-year intermolt (Tables 4). Growth patterns and size increments for both the males and females in Bonne Bay are similar during the immature stage (I – VII) after which they begin to differ and must be looked at individually (Table 2). Early benthic stages tend to settle in areas of suitable temperature that offer the best protection from cannibalism and predation, smaller bodied and molting crabs are oftentimes found on complex (boulder, cobble) substrates (Kruse et al., 2007, Comeau et al., 1998, Sainte-Marie and Hazel, 1992).

Table 4. Growth schedule for both males and females from Comeau et al. (1998) works in Bonne Bay, Newfoundland suggesting a 6-month intermolt from instar I – V, followed by an annual molt beginning at instar VI.

Instar	Month/Season	Approximate Age and Size
I	September	3-5 months – 3.0 mm cw
	Suggested winter molt	
II	May	1 year – 5.0 mm cw
	Suggested summer molt	
III	September	1+ year – 7.0 mm cw
	Suggested winter molt	
IV	May	2 years – 9.8 mm cw
	Suggested summer molt	
V	September	2+ years – 14.9 mm cw
	Suggested winter molt	
VI	May	3 years – 21.6 mm cw
	Suggested annual molt	
VII	May	4 years – 28.0 mm cw

Dates of instar occurrences as well as sizes may vary based on location; there is a high degree of variability between the north and south in the Gulf of St. Lawrence.

Females remain immature after instar VII and Comeau et al. (1998) infers that females molt each year until they reach the terminal molt (molt to maturity), which they submit occurs around instar X or XI, or ages 7 and 8 years respectively (Table 1, stages 12 and 13). With a life expectancy around 12 – 13 years, it is suggested that females can live up to 5 or 6 years after their terminal molt (Comeau et al., 1998, Kruse et al., 2007).

In male snow crabs, the onset of gonad maturity appears to influence growth at molt (Table 1, stages 12 – 14). As observed by Comeau and Conan (1992) and Sainte-Marie et al. (1995), the first critical molt or juvenile molt is achieved at the seventh molt between instars VII and VIII. The growth pattern in juvenile males from instars X – XII (approximately 7 – 9 years old), seems to be dependent upon density depended factors. Comeau et al. (1998) observed within Bonne Bay that juvenile males could (*i*) reach terminal molt, (*ii*) molt and stay juvenile (instars X – XII), thus retaining the possibility of future growth, or (*iii*) skip molting (growth inhibition). Elner and Beninger (1995) proposed two mutually exclusive hypotheses to identify what triggers the terminal molt, (*i*) failure of juvenile males to copulate with trigger the molt to maturity and (*ii*) juvenile males that do copulate will molt to maturity. The rational for the first hypothesis is that unsuccessful juvenile males will greatly increase their increase reproductive success by achieving mature male status. Adversely, already successful males will reach terminal molt rather than risk mortality by continuing to molt, in contrast with unsuccessful juvenile males that will increase their chances of mating by achieving a larger size before becoming mature. Comeau et al. (1998) suggests under a competitive reproductive environment, juveniles males will continue to grow to larger sizes before reaching terminal molt, which is in accordance with the second hypothesis proposed by Elner and Beninger (1995). Terminal molt in male snow crabs has been shown to take place between ages 8 – 10 (instars XI – XIII) as stated by Pinfold (2006); slight deviations to the final instar stage are shown in Table XX.

1.2.2 Molting

During times of molting – or ecdysis, crabs are white and soft-shelled, and is a period that may last several months. During this phase the crabs have little meat and experience increased susceptibility to predation and cannibalism (FRCC, 2005). Ecdysis allows not only for growth but also allows damaged tissue and missing limbs to be regenerated or substantially re-formed. During the molt cycle the epidermis of a crustacean periodically replaces the animal's entire cuticular surface (Halcrow and Steel, 1992). That stated, cuticle deposits might also be found during intermolt periods in response to localized damage, such as when limbs are autotomized, new cuticle forms as a thin layer beneath the autotomy membrane and as the covering of the regenerated limb within the limb base[3] (Adiyodi, 1972, Bliss, 1960, Halcrow and Steel, 1992, Hopkins, 1988).

During the terminal molt, the abdomen of the female widens substantially in order to accommodate carrying eggs. In the male snow crabs, the claws enlarge for mating and the male crabs reach their maximum size, ranging anywhere from 95 mm cw up to 140 mm cw. Once a snow crab reaches terminal molt the ability to regenerate limbs that may have been damaged or autotomized is lost (Conan et al., 1996). Old-shelled, post terminal molt, individuals often display a heavy cover of epibionts along with an abraded decalcified carapace and missing limbs due to fights between males during mating or nonfatal encounters with predators.

1.3 North Atlantic snow crab fisheries

1.3.1 Newfoundland and Labrador

The largest snow crab fishery in the North Atlantic takes place along fishing grounds of Newfoundland and Labrador. The Canadian snow crab (and other shellfish) fishery is organized and carried out much differently than the Barents Sea fishery which is currently

[3] An example of this can be seen in section 2.3 Figure 12.

under development. The full-time fleet is comprised mainly of vessels in the 17 – 20 m range (55 – 65 feet) and fishes in offshore waters (beyond 50 miles) (Pinfold, 2006). Currently there are 3,400 fishing licenses and it is estimated that ca. 1.2 million traps are deployed annually (Winger et al., 2015). Canadian regulations dictate crabs be landed live; many are kept on ice in the holds of the boat while other vessels have saltwater circulation systems that maintain the quality of the crabs until processing, which usually happens within hours of their delivery to the processing plant (DFO, 2015e). There were 86 active processing plants in the province in 2014 which employed approximately 17,500 people (DFO, 2015c). The east Canadian snow crab fishery developed rapidly after the cod-collapse in the early 1990s and the shellfish volume reached a peak of 200 thousand tonnes in 2006, of which, nearly 25% was snow crab. In 2014, the snow crab landings topped out around 50,000 tonnes (approximately 33% of all shellfish), which was nearly 48% of the total value of all landed shellfish (Figure 2) (DFO, 2015c).

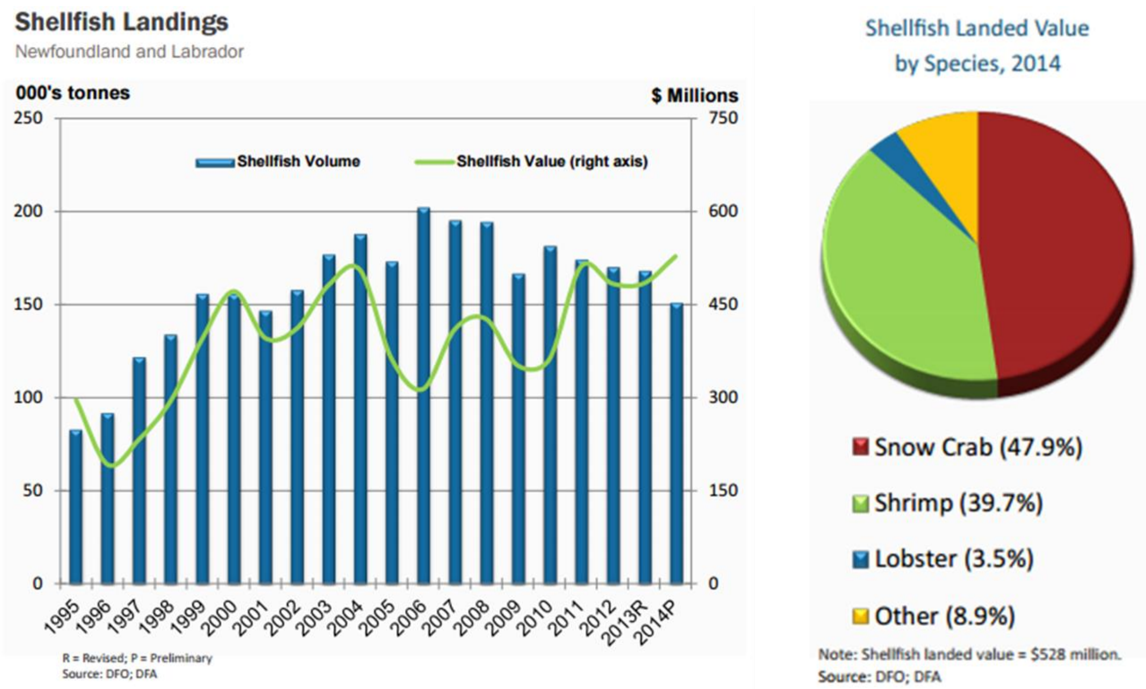

Figure 2. Shellfish Landings from 1995 – 2014 and 2014 Shellfish Landed Value by Species for Newfoundland and Labrador (DFO, 2015c).

1.3.2 The Barents Sea

A commercial fishery for snow crab in the Barents Sea has been under development since 2012. At present, a management plan has not yet been developed, a TAC has not been implemented and there are no direct regulations in the snow crab fishery. Norwegian authorities have the ability to limit effort by requiring all vessels intending to harvest snow crab in the Barents Sea be in possession of a license. It is infeasible to establish a complete picture of the Barents Sea snow crab fishery regarding participation of nations, companies and vessels, the number of pots deployed, catches/landings, etc. However, in Norway, total landings for 2014 was registered at 4,290 tonnes from six Norwegian vessels and eight vessels from Spain, Lithuania and Latvia. Presumably, the fishing is being performed in the "Loophole" (Norwegian: Smutthullet), a 67,100 km^2 area in the central Barents Sea between the Norwegian Economical Zone (NEZ), the Svalbard Zone and the Russian Economic Zone (REZ) (Figure 3). This area has up to now been acknowledged as international waters or "high seas." This Loophole, which is outside both the Norwegian and Russian Federations EEZ, but inside the continental shelf, creates a special legal case for the Barents Sea snow crab. In recent negotiations between Norwegian and Russian authorities, it has been agreed upon that snow crab are considered a sedentary species[4] resource and the right to management is defined by the continental shelf (Fenstad, 2015b). As part of the Barents Sea Treaty, the Russian Federation has possession of the majority of the continental shelf, therefore giving them sovereign rights over sedentary species and thereby exclusive access and jurisdiction (Henriksen and Ulfstein, 2011, Molenaar, 2015). There is concern that Russia may exclude foreign vessels in the near future (Fenstad, 2015c).

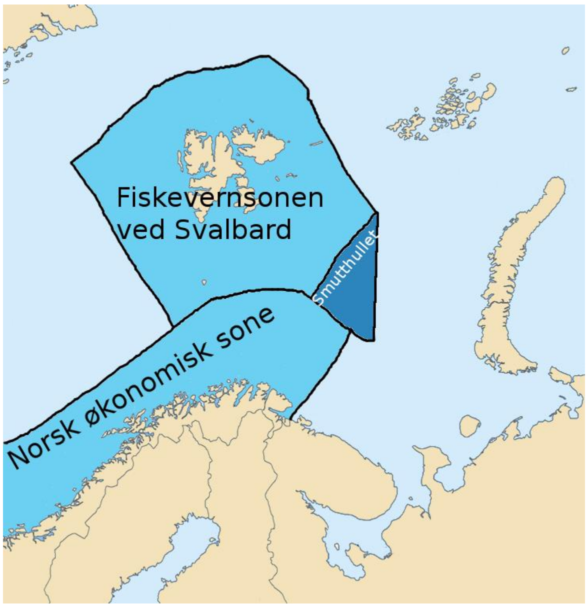

Figure 3. Map of the "Loophole" (Norwegian: Smutthullet) located between the Norwegian Economic Zone (Norsk økonomisk sone) (NEZ), the Svalbard Zone (Fiskevernsonen ved Svalbard) and the Russian Economic Zone (REZ) to the east (Ree, 2009).

[4] A sedentary species is an organism, which, at the harvestable stage, either are immobile on or under the seabed or are unable to move except in constant physical contact with the seabed or the subsoil (Whiteman, 1958).

Harvest of snow crabs in the Barents Sea is primarily being done with the Canadian style conical pot, gear aside; there are few similarities to the Canadian fishery. Thus far, the snow crab fishery has primarily been taking place during the dark periods of autumn and winter. Approximately 85% of the catches are being processed on board and landed as frozen products (packed for consumer markets). Due to long transport distances from the fishing grounds and energy consuming live crab-holds in fishing vessels, this fishery does not favour a land-based processing industry as is seen in Canada.

In Norway, only 20 vessels have been given fishing licenses for snow crab and most of these vessels range in size from 40 – 60 m in length. Norges Råfisklag (2015) is predicting the Norwegian snow crab landings to be between 8,000 – 10,000 tonnes in 2015. In the Russian Federation, it is believed that there are 14 Russian crab vessels operating in the REZ and landing their catches in Russia. The Russian government recently approved a proposal to establish the fee rate for fishing of the *opilio* snow crab in the Barents Sea (Anonymous, 2014a). With this fee comes the right to secure shares of the commercial quotas and begin fishing for snow crabs. The state agency "Rosrybolovstvo" has allowed 1,100 tonnes[5] of snow crab to be caught in the Barents Sea in 2015, there is a 100 mm minimum size limit and females and juveniles must be returned to the natural environment (Anonymous, 2014b, Anonymous, 2014a).

1.4 Management of the snow crab

1.4.1 Canada

In Canada, the fishing seasons are established each year as part of the annual harvest plan for each fishing area, with the seasons varying significantly depending on the area. There are approximately 60 Snow Crab Management Areas in Canada spanning four Fisheries and Oceans Canada (DFO) regions (DFO, 2014b). In the main fishing area of the Gulf of St. Lawrence, harvesting typically takes place during the spring in April through early summer. This helps avoid harvesting during the mating season of first time spawners in late winter and early spring it is also a time when molting, soft-shelled, crabs are typically not caught (FRCC, 2005). Both ice conditions and the economic barriers created by other more competitive

[5] A 2015 Russian TAC of 1,100 tonnes in the Barents Sea seems quite small considering there were 4,290 tonnes landed in Norway during 2014. Speculation this could be an individual quota and not TAC was not able to be verified at this time.

fisheries (lobster) in some of the harvest areas can push the start date as late as July causing the fishery to run into the early fall. This increases the chances of fishermen catching soft-shelled crabs, which (if detected) can lead authorities to close the fishery. The annual snow crab harvest is managed based on Total Allowable Catch (TAC) established each spring for designated snow crab fishing areas. Each licensed fishing enterprise is allocated a specific tonnage of snow crab to be harvested. The individual allocation generally depends on the size of vessel operated, its history of participation in the fishery, and the number of licenses participating in the fishing area. In addition to individual allocations, communal licenses[6] are issued to qualified First Nations Aboriginal communities (FRCC, 2005). All vessels targeting snow crab are required to have instillation and continuous operation of vessel monitoring system (VMS) equipment while engaging in fishing activities and all snow crab catches are independently monitored at dockside for quota management purposes (DFO, 2015b). The Canadian fishery is conducted with one gear type, namely single conical shaped traps (pots) although some harvesters use rectangular shaped traps. The twine mesh in the traps is regulated to a minimum size of 5 ¼ inches to select male snow crab greater than or equal to the legal size limit of 95mm cw (FRCC, 2005). In the province of Newfoundland and Labrador, biodegradable twine on traps is a mandatory condition for a license in order to disable and allow for the release of any catch should the gear become derelict (DFO, 2015a), however, this condition is not required in the other three fishing regions at this time. Harvest of females and soft-shelled males are prohibited. Within the larger crab fishing areas, grids are used to assess the incidence of soft-shelled (recently molted) crab. If a high proportion of soft-shell crabs are caught, the fishery will close for the remainder of the season in that particular grid. The closure thresholds differ by management area, but in most cases, when 20 percent of the catch in a grid is comprised of soft shell crabs, that grid is closed (DFO, 2014b).

1.4.2 United States

In the United States, the Bering Sea snow crab fishery season begins October 15 and runs until May 15 in the Eastern sub-district and May 31 in the Western sub-district, this is done to maximize meat yield and to minimize handling of the soft-shelled crabs (ADF&G, 2014, ADF&G, 2015, Miller, 1976, NOAA, 2015b). Total Allowable Catch is broken down into

[6] The communal license approach in the First Nations community is a process whereby a fishery is prosecuted by individual enterprises but part or all of the proceeds are shared on a community wide basis, usually in support of infrastructure development.

Individual Fishing Quotas (IFQ) and Community Development Quotas[7] (CDQ). Individual Fishing Quotas and Individual Processing Quotas (IPQ) are issued annually for the crab quota fishery license holders, a Federal Crab Vessel Permit (FCVP) with a VMS, observer coverage and logbook reporting is also required for owners of any vessel used in the rationalized crab fisheries (NOAA, 2015a). Fishing gear is limited to traps, ring nets and diving; controlled harvest levels help ensure enough males are left on the grounds for breeding; females may not be taken; and subsistence fishing is limited to 30 crabs per day (Miller, 1976). Gear restrictions include pot limits, degradable escapement mechanisms and web specifications (NOAA, 2015b). Legal minimum size for the Alaskan snow crab fishery, is 78 mm (3.1 inches) carapace width (cw) (ADF&G, 2015). However, the aforementioned not withstanding, an economical minimum size of 102 mm (~4 inches) cw is in place and generally supersedes the 78 mm cw size limit (NOAA, 2015b, NOAA, 2015a, Otto, 1989). Within the fishery, in-season adjustments may be made based on factors including, but not limited to; overall effort, relative abundance, and the proportion[8] of soft-shelled crabs ad rate of dead loss (ADF&G, 2015).

1.4.3 Other Countries

Limited information on the management practices was found for Russia and Japan in conjunction with the research conducted for this paper. Of the information available, it was found that in the Karaginsky sub-zone of Russia, and presumably throughout eastern Russia, harvest of crabs is limited to traps, females and by-catch of juvenile (sub-legal) is prohibited and must be returned to the sea immediately. When by-catch of juvenile crabs is more than 8% by fishing effort, vessels must relocate to a distance not less than 5 nautical miles from previous set (Anonymous, 2014b). In the Karaginsky sub-zone there is a minimum size limit of 100 mm cw, there is also a minimal[9] daily catch per vessel of 0.63 tonnes and fishing for snow crab is prohibited in the sub-zone located to the east of 168°55’ E.

[7] CDQs allocates a percentage of all Bering Sea and Aleutian Islands quotas to eligible communities. The purpose of the CDQ program is (i) to provide eligible western Alaska villages with the opportunity to participate and invest in fisheries in the Bering Sea and Aleutian Islands Management Area; (ii) to support economic development in western Alaska; (iii) to alleviate poverty and provide economic and social benefits for residents of western Alaska; and (iv) to achieve sustainable and diversified local economies in western Alaska (NOAA Fisheries, 2015).

[8] Specific proportions were not listed within the regulation.

[9] Literature from (Anonymous, 2015b) indicated minimal daily catch limits, not maximum, although this could be a misprint.

The Western Japan Sea snow crab fishery runs from November 6th for hard-shelled males and December 21st for soft-shelled males through March 20th, while females can be harvested from November 6th until January 10th (Yamasaki, 2011). A TAC system was implemented in 1997, where the TAC is allocated by the central government of the union of trawl fishermen into six coastal district management bodies, each district then allocates their respective TAC to the licensed fishermen (Datta et al., 2012). The Japanese snow crab are fished using trawl, seines, gill nets and traps. There is a 90 mm cw minimum size limit and within the Danish seine fleet[10], immature females or adults with orange-colored eggs are prohibited from being harvested (Yamasaki, 2011). In addition, there are maximum catch per trip limits, which limit the number of individual soft-shelled males and females that may be harvested within a given period of time.

1.5 Research objectives and limitations

In the Nguyen et al. (2014) experiment, researchers looked into snow crab interactions with the mobile gear sector as there were concerns raised by the industry that shrimp trawling represents an important source of unaccounted mortality, negatively affecting the snow crab population. While little is yet known about the recent establishment of the non-native snow crab in the Barents Sea, Norwegian stakeholders with an interest in this fishery could be facing a similar predicament as the potters in Northeastern Canada. A snow crab fishery in the Barents Sea has the potential to be a very profitable fishery, as it is elsewhere in the higher latitudes of the Northern hemisphere (Fenstad, 2015d). The concerns of mobile gear negatively affecting snow crab populations should be addressed and considered in conjunctions with discussions on regulations and establishment of a snow crab fishery in the Barents Sea.

The first objective of this study is to conduct video observations of individual snow crabs interacting with the mobile gear in order to look into how the snow crab react to encounters with groundrope used in the traditional commercial fleet of the Northeast Barents Sea.

Two different types of groundrope were used to quantify the rate of cod (*Gadus morhua)* and haddock (*Melanogrammus aeglefinus)* escapement underneath the center part of the fishing line for a simultaneous studying being conducted on board the vessel.

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[10] It was unclear from the source if the regulations pertaining to immature or egg-bearing females and catch limits applied only to the Danish seine fishery or if they were applicable for all gear types.

The second objective is to determine what, if any, factors might influence injury(s) sustained by snow crab during interaction with the mobile gear.

> **H_0**: There is no connection between position of the collection bag, and or groundrope type, and or weight, and or carapace width, and or sex, and or duration of tow, and or average speed, and or average temperature, and or average depth, and or maximum depth, and or if the tow was filmed on the presence of an injury.
>
> **H_A**: There is a connection between position of the collection bag, and or groundrope type, and or weight, and or carapace width, and or sex, and or duration of tow, and or average speed, and or average temperature, and or average depth, and or maximum depth, and or if the tow was filmed on the presence of an injury.

Literature pertaining specifically to snow crabs in the Barents Sea is limited due to the species recent appearance in the area. Studies conducted in areas with native populations can prove helpful in many ways; however, for information pertaining to topics such as, local distribution, which is still in the process of being established, these materials are ineffective, with the exception of providing a backdrop for suitable habitat. While the joint Russian-Norwegian ecosystem surveys have permitted closer evaluations of snow crab distribution, the full extent of their range is yet to be determined as they are still establishing themselves in the area. Locating a study area that contains *C. opilio* is therefore to a certain extent dependent upon fishing vessels in the area at the time relaying catch information as well as local weather and ice conditions, which at the time of the study in November, can be highly variable. The aforementioned distribution encumbrance as well as gear complications among other factors in turn can limit the total number of crab harvested during the survey.

This study is limiting the focus area of video analysis and collection of snow crabs to the center 6.1 m section of trawl gear. By not looking at all sections, there could be bias on not only behavioral reactions but also among the distribution of injuries sustained by the crabs and the total number of crabs collected. The total width of a bottom trawl presents a range of different obstacles for crabs to pass over, under or around (Rose, 1999). By far the largest portion of the area swept by most bottom trawls is covered by the sweeps, which connect the trawl net to the trawl doors. For this survey, the trawl is set-up in a semi-pelagic configuration with the doors 5.0 m off the ground. This is not the typical set-up of the fleets in the area, which traditionally bottom trawl using their gear as a means of herding fish into the net, thus increasing the chance of interaction between the crabs and gear in the benthic set-up.

Video analysis will be dependent on the amount and the quality of video produced by the study; this can be limited by camera and or lighting performance, positioning, and or sedimentation among other factors. Two of the cameras used come standard with a waterproof housing capable of withstanding depths up to 60 m, this however is not sufficient for the survey which takes place in an area with an average depth of 230m (maximum of 500 m). Special housings had been developed and tested during previous deep-water trawl experiments conducted by the University of Tromsø (UiT) resulting in both successful video and a flooded camera. The lighting units are also susceptible to the pressure at depths. In addition, both the camera and lighting system are also vulnerable to battery life as well as electronic malfunctions and overall placement positioning with respect to movements as the trawl is being towed. Sediments suspended in the water column either due to previous trawl activity in the area, turbidity cause by the current trawling experiment or by the movement of fish can also affect the quality and quantity of video available for analysis.

2.0 Methods and Materials

The experiment was carried-out from the 17th to the 24th of November 2014, onboard the R/V *Helmer Hanssen,* a 64 meter multi-purpose vessel designed for full scale trawling operations (UiT, 2013). The vessel is owned and operated by UiT The Arctic University of Norway. Due to ice conditions in the area at the time, the vessel in addition to the commercial fleet were displaced southwards. Fishing trials were conducted in areas southeast of Hopen Island (76°N – 28°E) and along Sentralbanken (75°N – 35°E) (see map Figure 4). Along these fishing grounds, commercial fleets target aggregations of pre-spawning Northeast Arctic cod haddock, and shrimp (*Pandalus borealis*) and in the northeastern locations of Sentralbanken, the upcoming snow crab pot fishery is under development.

2.1 Study area

The area of study for this survey is located in the Barents Sea, southeast of Hopen and around the Sentralbanken (Figure 4). Due to sea ice conditions in the area at the time, the study, which was intended to take place around 77°N 33°E, was forced to move south along with all other commercial fishing activities. Multiple studies were taking place on board at the time of data collection, and locations for trawls were determined on board the vessel based on historic data/knowledge of the cod and haddock distributions as well as information on the activity of the (Norwegian) fish and crab vessels in the intended sample area.

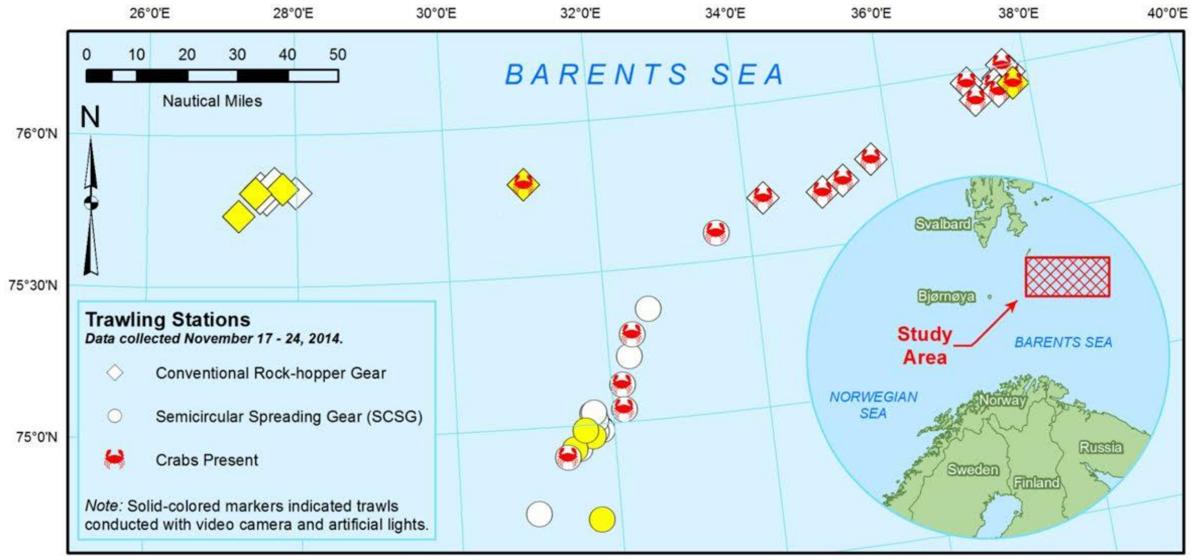


Figure 4. Map of the study area with valid trawl stations, where snow crab were present in the trawl and trawls conducted with video.

Communications between commercial crab potters and research crew took place before departure, during October and November, in order to get an idea of where snow crabs were congregating. Once within the sampling area, the intention was to deploy sets of crab pots in order to verify the presence or absence of snow crabs in the region. Five baited pots, placed along a chain 100.0 meters apart constituted one set of traps. However, due to drift-ice problems, crab pots could not be deployed in the area of the Sentralbanken, leaving only two sets on the west coast of Svalbard that were allowed to soak for approximately 20 hours each. An important qualifier for the study was visualization of the bottom sampling area in front of the groundrope and those snow crabs coming into contact with the trawling gear. Benthic sediments are easily disturbed by bottom gear and can lead to poor or zero visibility with camera equipment. Caution was taken to make sure trawling had not recently occurred within the sample area and contact was made with the commercial fleet to see if anyone had been in the area trawling. Normally, the area would have been checked for commercial pots to make sure they would not be in the way of the trawling study being conducted; however due to the ice conditions mentioned above, this was not an issue during this survey.

2.2 Trawl set-up

2.2.1 Overall set-up

A modified two-panel version of an Alfredo No. 3 fish trawl was used in a semi-pelagic configuration (Figure 5). At a towing speed around 3.5 knots there was an otter board spread of approximately 165.0 m, a wingspread of the trawl around 18.0 m and a trawl height near 4.5 m.

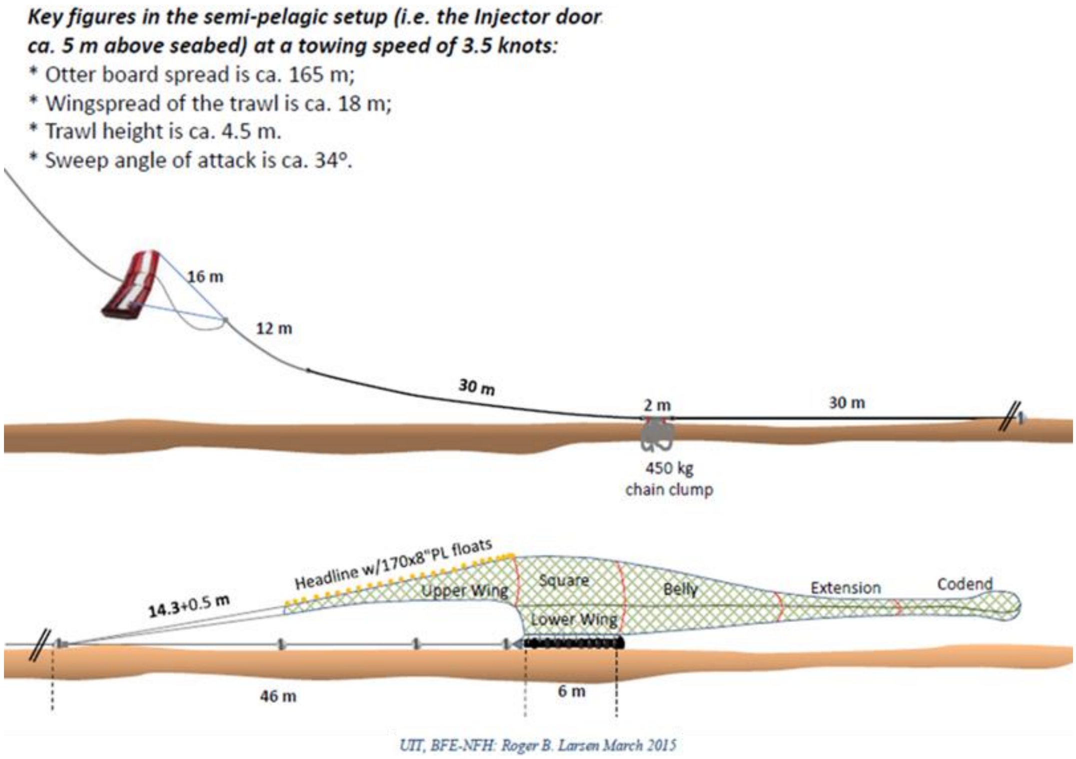


Figure 5. Alfredo No. 3 fish trawl in the semi-pelagic set-up (Larsen et al., 2015).

Figure 6 shows the details of how the trawl was rigged with the Injector XF9 high aspect otter boards (7.0 m^2 and 2200 kg) (1) kept approximately 5.0 meters above the seabed. The backstraps (2) were 15.9 m long and connected to the bridles by 12.0 m long Ø19 mm connector chains (3). There were two sweeps (4), each were 30.0 m Ø30 mm with a 2.0 m Ø19 mm chain in the middle connecting the two. Attached to the previously mentioned 2.0 m attachment chain, a 450 kg chain clump (5) was inserted in order to ensure proper bottom contact of the ground gear. In the semi-pelagic operation, it was assumed that the sweep and connection to the otter boards (total length of 30.0 m + 12.0 m +16.0 m) is off the seabed during towing. The distance between the chain clumps were calculated to be around 100.0 m with the setup, giving an approximate sweep angle of 34°. The leading section of the ground gear (6) is comprised of two 46.0 m long Ø19 mm chains with four 21” steel bobbins placed along at approximately 11.0 m intervals that run along either side of the configuration. The distance between the chain clump (5) and the footrope was 76.0 m. The length of the double bridles from the Danleno[11] to the headline are 14.3 m + 0.5 m each, with an upper wing of 17.2 m (Figure 5). The central section of the groundrope (7) is where either the conventional rock-hopper gear or the semi-circular spreading gear (SCSG) was attached to the 18.9 m long fishing line with Ø10 mm Quick-links (*see section 2.2.2*). The Alfredo No. 3 trawl (8) was attached with a 18.9 m fishing line and a headline of 36.5 m fitted with 170, 8” (200 mm) floats (approximately 460 kP lifting capacity) (Figures 5 and 7). The Alfredo No. 3 employed is designed for selectivity studies, and included an 80.0 mm Ø3.0 mm PE body mesh size used for the trawl wings, panels, belly and extension. In the trial, a conventional 135.0 mm mesh size codend made of Ø8.0 mm PE (Euroline Premium) with an overall dimension of 60x60 mesh was attached. The mesh size used was selected for the retention of snow crab as well as cod and haddock that would also be encountered during a simultaneous study taking place during the cruise to investigate the escapement underneath the fishing line in the commercial trawl fishery. Minimum escapement of any sized snow crab, even with a 135.0 mm mesh codend was assumed, this of course would have been different in pot with more open meshes. The headline of the retainer bag (9) was attached to the 6.3 m center section of the fishing line of the main trawl (*see section 2.2.3*).

1) Injector XF9 high aspect otter boards, 2200 kg; area 7,0 m^2
2) 15.9 m backstrap
3) 12 m Ø19 connector chain
4) 30.0 m Ø30mm sweep + 2.0 m Ø19 chain + 30.0 m Ø30mm sweep
5) 450 kg chain clump
6) 46,0 m Ø19 chain + 4 x 21" steel bobbins
7) 3x6.0 rockhopper (21") or 3x6.0 semidisc gear (20"), see construction drawings and details.
8) Alfredo No. 3 fish trawl, see contruction drawing and details
9) Escapee retainer bag, see contruction drawing and details

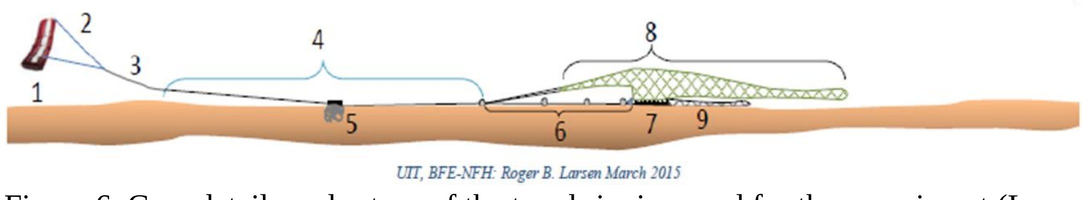


Figure 6. Gear details and set-up of the trawl rigging used for the experiment (Larsen et al., 2015).

[11] A spreading device located directly ahead of either net wing.

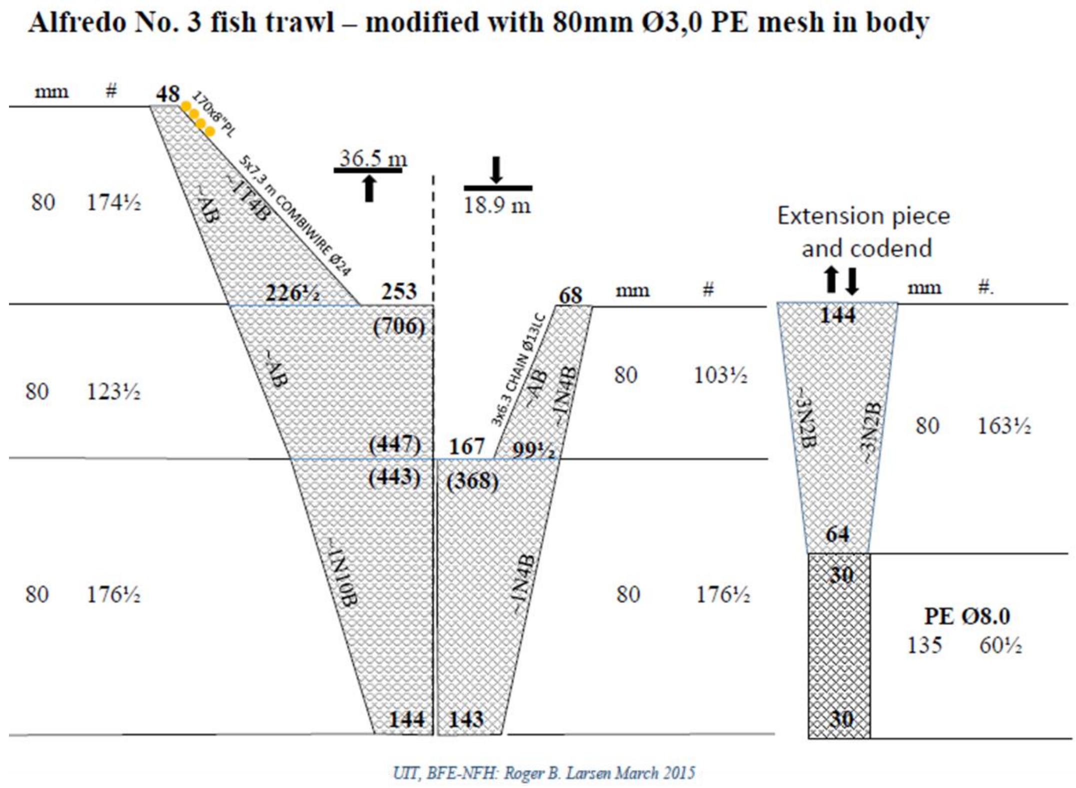
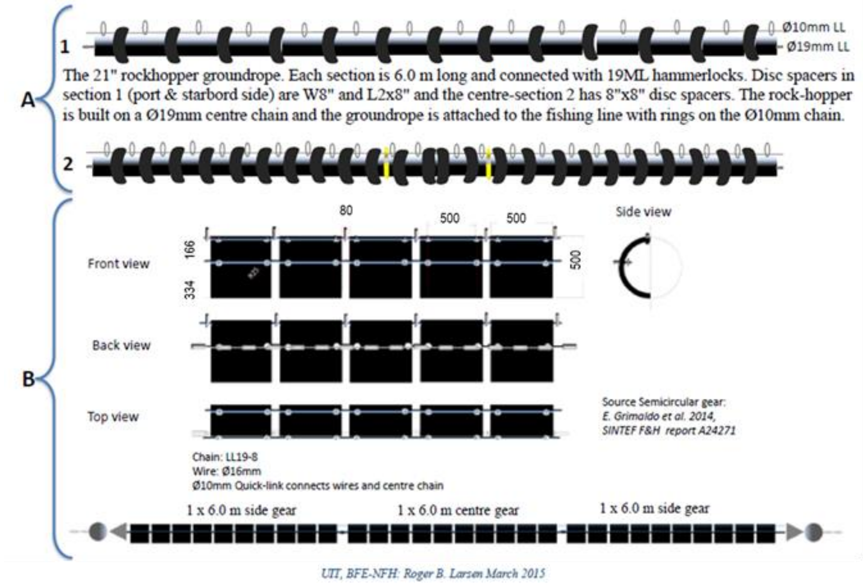


Figure 7. Setup of Alfredo No. 3 fish trawl (Larsen et al., 2015).

2.2.2 Groundropes

During the experiment, two different groundropes were used along the 18.9 m long fishing line consisting of three sections measuring 6.0 m in length; a standard 53.3 cm (21") rock-hopper groundrope and a 50.8 cm (20") semi-circular groundrope (SCSG) (Figure 8). The rock-hopper gear was used during the first part of the experiment (Table XX). The distance between discs was 40.6 cm (16") for both the port and starboard sections and utilized W8" and L2x8" disc spacers (Figure 8, A1). In the center section, a distance of 20.3 cm (8") was maintained with two 8x8" disc spacers (Figure 8, A2). The rock-hopper gear was built on a Ø19 mm center chain and each of the 6.0 m sections were connected with 19 ML hammerlocks. Attached to the upper part of the discs of the groundrope was a Ø10 mm chain equipped with steel rings for easy attachment to the fishing line with Quick-links. This rigging is similar to the setup used in the commercial trawl fleet.

In the latter part of the experiment a 18.9 m long semi-circle groundrope containing three 6.0 m sections was used (Figure 8, B). Developed by Grimaldo et al. (2013), the SCSG made with 50.0 cm high, 50.0 cm long, 3.4 cm thick sections made out of high-density polyethylene (HDPE) pipe with a distance of 8.0 cm between each of the elements. The SCSG was built on a LL19-8 chain, and connected with a Ø16 mm wire, in addition, there was a Ø10 mm chain equipped with steel rings for easy attachment to the fishing line with Quick-links.



A) The 21” (53.3 cm) rockhopper gear and **B**) The 20” (50.8 cm) semi-circular ground-rope

Figure 8. Construction of the two different groundropes for the Alfredo No. 3 fish trawls (Larsen et al., 2015, Grimaldo et al., 2014).

2.2.3 Retainer Bag

The purpose of the retainer bag used in the experiment was to sample snow crab or fish escaping below the central section of the fishing line of the Alfredo No. 3 trawl. The construction was inspired by retainer bags developed by Ingólfsson and Jørgensen (2006), where they chose to use fine-meshed (50.0 mm) bags built from thin, Ø2.5 mm PE net, such nets mentioned would not work in the environmental conditions presented by the study area due to evident risks of filling the bags with clay and stones. The weights of clay and stone coupled with abrasion along the seabed would cause the thin PE twines to break easily. The construction of the bag used for the trials was made from stronger and more durable materials. Double Ø5.0 mm by 155.0 mm meshes (inner mesh 135.0 mm) PE was used in the upper and side panels, while double Ø6.0 mm by 155.0 mm meshes (inner mesh 135.0 mm) PA was used in the under panels and as a protection mat along its codend (Figure 9). In addition to utilizing more durable materials in the under bag construction, an opening on the underside of the retainer bag (see the diamond shape opening on the drawing in Figure 9), just prior to the codend, was included to allow for the release of rocks. A positively buoyant panel located on the underside of the retainer bag covered the opening and was designed to prevent the escapement of crabs and fish; however, it would open under the weight of larger stones. With the 135.0 mm mesh size that was selected for the codend, it was assumed the size composition of fish and crab would allow no or minimal escapement. It was also assumed that the relative large mesh size possibly could allow some of the clay to filter out through the codend meshes.

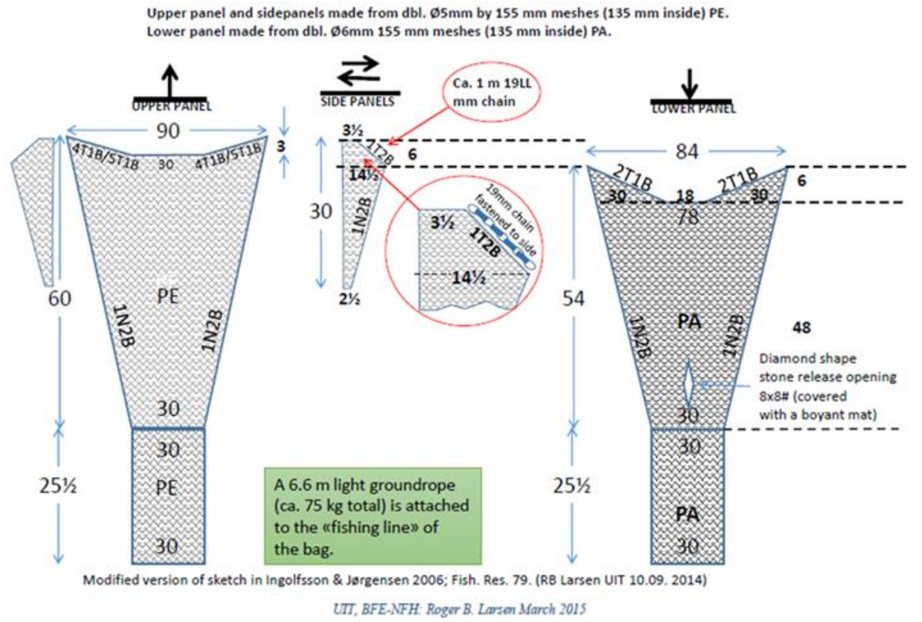


Figure 9. Construction of the retainer bag (Larsen et al., 2015).

Due to heavier construction and concerns about the drag forces and impact to the overall trawl configuration, only one single retainer bag covering the track of the center section of the groundrope was used. The 6.6 m fishing line of the retainer bag was made of Ø18 mm combi-rope and was attached to the trawls' groundrope by GM16 locks connected to the eyes located on either end (Figure 10). The ground gear consisted of 19.0 mm LL chain with steel fillers inserted along its line. Total weight of the groundrope was approximately 75 kg. A 10.0 kg clump of chain was added to both sides of the retaining bag's wingtips in order to ensure proper bottom contact.

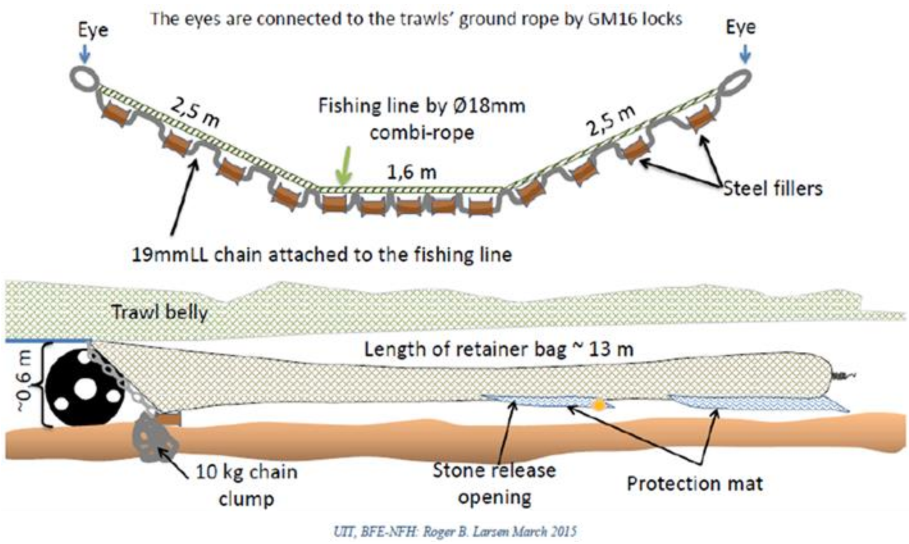


Figure 10. Details of the groundrope and the mounting of the retainer bag underneath the trawl (Larsen et al., 2015).

2.2.4 Codend mesh size

The reasoning for the relative large mesh size in the codend has to do with the nature and purpose of the experiments that were taking place, i.e. retention of large cod and haddock as well as snow crab in addition to the environmental conditions. In the simultaneous experiment that was being conducted, Brinkhof (2015) justified the mesh size in accordance with the former minimum legal mesh size[12] of 135 mm, in accordance with the Norwegian Law for Exploration of Sea Resources. Also taken into consideration was that the codend mesh size should be equal to the retainer bag behind the groundrope

Typical for these fishing grounds in the study area around Hopen and Sentralbanken (Figure 4) is a seabed with a mix of soft clay and rocks of various sizes. Practical experience from the trawl fleet is that clay and rocks seldom enters the funnel and codend of the trawl if a proper rock-hopper gear is used, while it is rather common to get stuck in clay banks with conventional otter boards and partly the sweeps. Normal procedures are hence to start haul-back immediately to check the gear for any damages, with the addition of the retainer bag there was an increased risk of damage to the trawl setup.

2.3 Data collection

Data collection for this thesis consisted of collecting both quantitative data – carapace width (mm) and weight (g); as well as categorical data – ground gear type (conventional groundrope

[12] Since 2011, the minimum legal mesh size was reduced to 130 mm, as referenced by Brinkhof (2015).

or SCSG), bag location (codend or retainer/collection bag), sex (M/F/Unknown) and injury type (I-IV). Injuries were classified similarly to Rose (1999), by their location (legs, carapace and abdomen) (Table 5, Figure 11). Because snow crabs can autotomize (drop) injured legs, crabs with indications of healed autotomies were classified the same as crabs with no damage (Figure 12). Autotomies that appeared to have happened during the trawl (i.e. did not show signs of healing) were classified as leg damage. Multiple injuries were categorized under the most serious apparent injury, i.e. a crab with a cracked carapace and a damaged/missing leg was classified as a carapace injury.

Table 5. Injury classification

Status	Injury
I	No Damage/ Autotomized Leg
II	Leg Damage
III	Carapace Damage
IV	Abdomen Damage

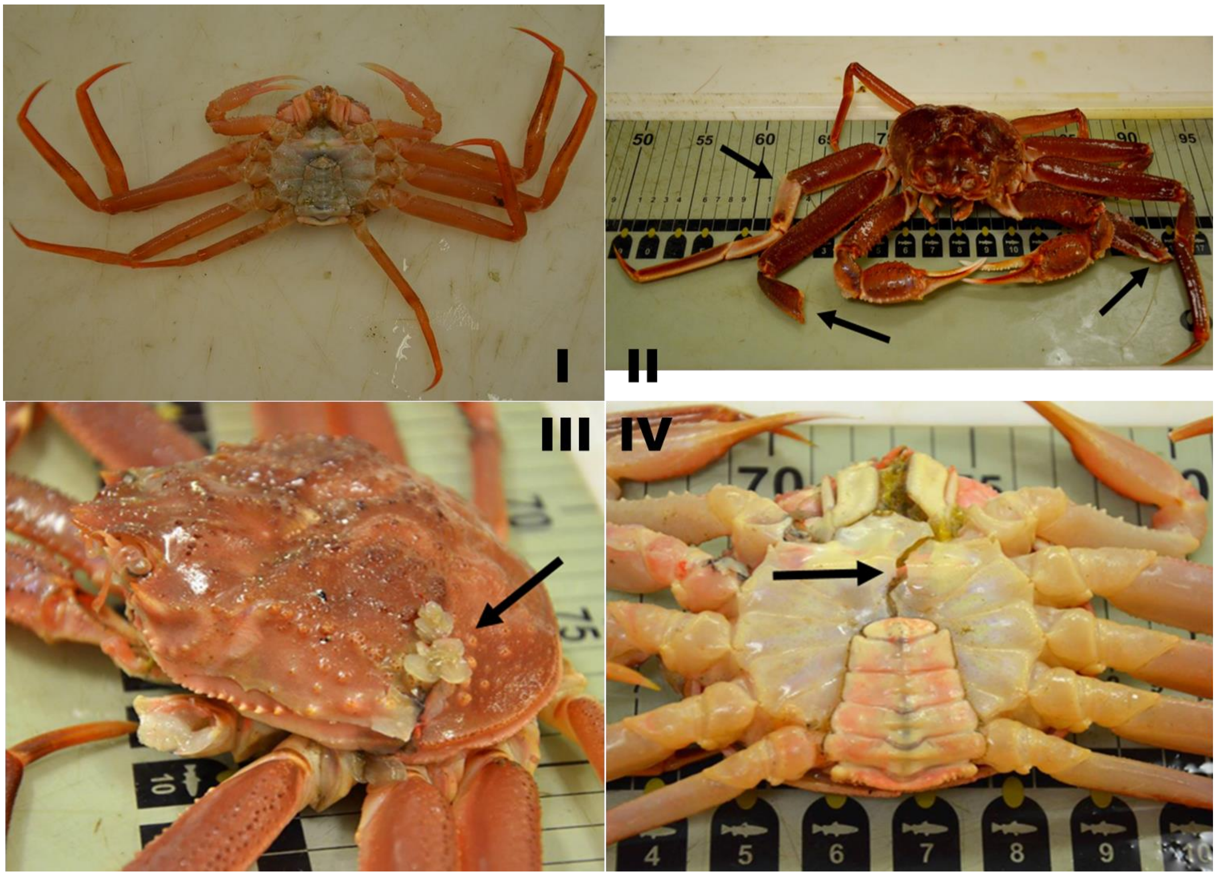


Figure 11. Examples of the injury classifications: No Damage/Autotomized Leg (I), Leg Damage (II), Carapace Damage (III) and Abdomen Damage (IV).

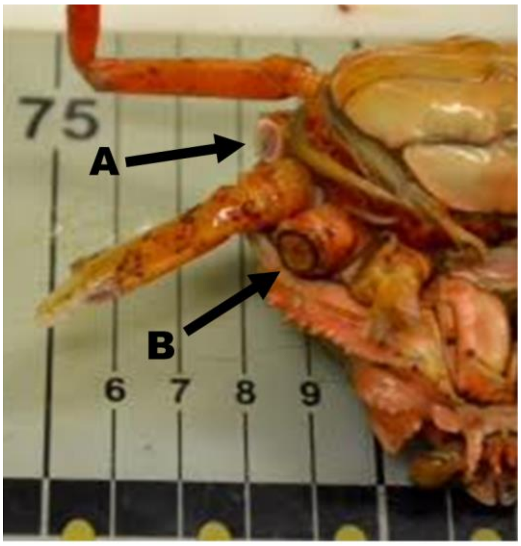


Figure 12. Example of both a new leg injury (A) and a leg injury sustained prior to encounter with trawl that has begun to heal (B).

2.3.1 Trawl monitoring

Marport and Scanmar trawl sensors located on the trawl doors were used to monitor the trawl and rigging configuration as well as temperature throughout the trawl survey (Figure 13) (Grimaldo et al., 2014). Marport sensors measured distance between doors, depth of doors and the height from the seabed. This was crucial in ensuring the doors were kept ca. 5.0 m off the seabed. The Scanmar sensor also measured the distance between doors.

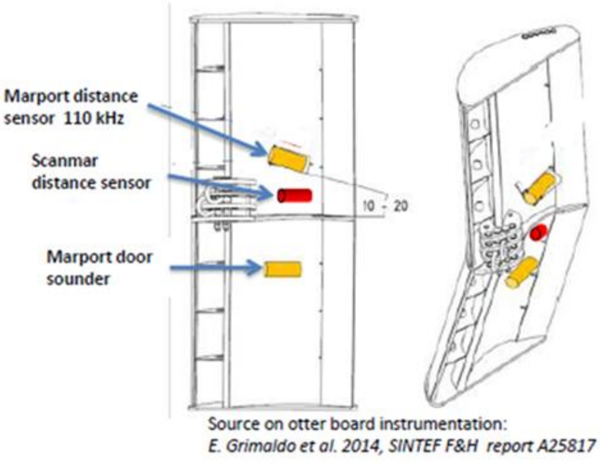


Figure 13. Marport (yellow) and Scanmar (red) sensor placement (Grimaldo et al., 2014).

2.3.2 Camera system and operation

This experiment was performed during a time of the year characterized by 24 hours of darkness along the fishing grounds in the northern Barents Sea as well as at great depths; therefore, artificial light was used in all underwater recordings. One of the biggest challenges with filming trawls is having mud-clouds (sediment-eddies) covering the observation area. On soft clay bottom, movements by fish close to the seabed can stir-up mud-clouds. Additional difficulties arise when artificial lights are used as reflections from particles in the water reduce the visibility. Observations were concentrated at the central part of the groundrope (i.e. in its full 5.0 – 6.0 m width during tows). Self-contained underwater camera systems, owned by UiT Norway's Arctic University was used for the experiment to monitor the center section of the trawl net that contained the following (Table 6, Figure 14).

Table 6. Camera and lighting system set-up used during trawling.

Position	Camera and lighting system set-up
1	SIMRAD OE 1324 low light camera with self-contained recorder unit • 2 x 9 W white neon lights • 600 lumen • 4000 Kelvin
2	GoPro cameras (Hero2 and Hero3) in special housing with depth rating of 240.0 m • MetalSub 50 W Halogen • 1500 lumen • 3200 Kelvin with difuse light beam
3	GoPro cameras (Hero2 and Hero3) in special housing with depth rating of 240.0 m • 4 x MetalSub 27 W LED • 2000 lumen • 5000 Kelvin with narrow light beam

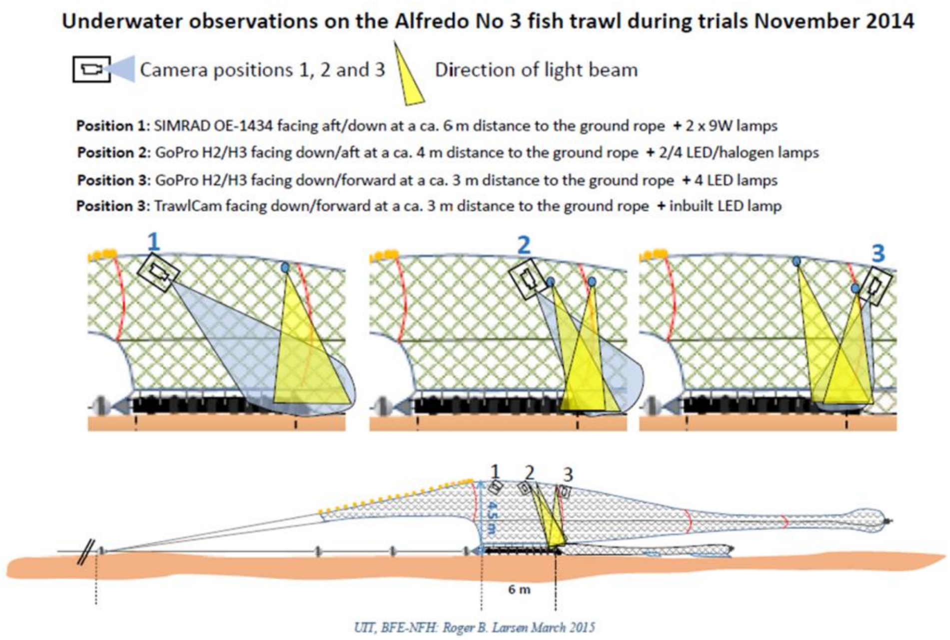


Figure 14. Trawl camera set up with light configuration, numbers are associated with Table 6. (Larsen et al., 2015)

2.3.3 Video Analysis

Analysis of the video footage was conducted using GoPro® Studio by reviewing the playback at a slowed down speed. As in Nguyen et al. (2014), when snow crabs were visualized on the screen time of first appearance, position relative to substrate (buried or on surface) direction the individual was facing, orientation of movement, direction of movement, and nature of encounter (i.e. type of encounter, duration of encounter, and fate of encounter). The nature of the individual crab's interaction was categorized as either (*i*) experiencing a direct encounter with the disc, (*ii*) experience an encounter with the spacer/travel chain, (*iii*) passing between the discs with no apparent encounter, or (*iv*) unknown because either the crab or the footgear left the field of view and the actual interaction could not be determined.

2.4 Statistical Methods

A multiple logistic regression was conducted using the statistical software SYSTAT® to predict the probability of independent variables having an effect on a dependent variable. For this experiment, the presence of an injury (Stages II-IV) or lack of injury (Stage I) was used as the binomial categorical variable and was tested against the following independent variables to see if there was an effect:

- position of the bag (codend or retainer bag),
- groundrope type (conventional rock-hopper gear or SCSG),
- weight,
- carapace width,
- sex (male or female),
- duration of tow,
- average tow speed,
- average temperature,
- average depth,
- maximum depth and
- filmed (yes or no; indicates presence or absence of external light).

Binary logistic regression was run and parameter estimates with a *p*-value greater than or equal to alpha ($\alpha = 0.05$) were considered not statistically significant. The parameter with the highest *p*-value was removed and the test repeated until only parameters with a *p*-value less than 0.05 remained. In addition, the odds ratio estimates were used to compare the relative odds of injury given the exposure to the variables. If the upper and lower 95% confidence interval encompassed the null value 1, then by proxy it was not considered statistically significant.

3.0 Results

The trawl was towed at a speed of 3.5 knots (1.8 $ms^{-1)}$. During periods of amplified wave action, trawl speed was increased from ca. 3.5 knots to ca. 3.7 knots, in order to mitigate the influence on the semi-pelagic otter boards. Increased wave action would cause the otter boards to deviate from the 5.0 m distance off the seabed. Overall, the average tow speeds for each of the hauls was roughly at 3.5 knots or below, this could be due to headwinds, currents and or wave height. Towing times were restricted to maximum 90 minutes and approximately 3 tonnes of fish (round weight) or shorter if catch rates were higher than 3 tonnes.

3.1 Trawl set-up

A total of 47 trawls were performed during the cruise. The first 25 hauls were performed the 17th of November through the 20th using the conventional rock-hopper gear followed by the SCSG being employed from the 21st through the 22nd of November for the remaining 22 hauls (Table 7). Of the 47 hauls, six were considered invalid due to technical malfunctions in the gear, such as; tears in the net, open codend, broken groundrope, large rocks in the net, etc. Tears discovered in the nets were mended before the trawl was redeployed. The chain connected to the ground gear of the retainer bag was cleaned and damages repaired prior to each deployment to ensure proper contact with the seabed.

Table 7. Details of the valid hauls, which include date and time, starting position of tow, duration, average speed, average temperature, average depth, ground gear type and number of snow crabs collected.

Haul #	Date (UTC)	Start Time (UTC)	Latitude (D°M.m)	Longitude (D°M.m)	Duration (h:mm)	Avg. Speed (kn)	Avg. Temp (C°)	Avg. Depth (m)	Gear Type	# Snow Crabs
1	17.11.2014	12:10	75°49.51 N	27°31.15 E	0:30	3.55	1.19	242.20	RH	0
2*	17.11.2014	13:56	75°49.25 N	27°49.20 E	1:03	3.39	1.17	237.79	RH	0
3	17.11.2014	15:46	75°48.46 N	27°59.65 E	1:11	3.54	0.99	237.33	RH	0
4	17.11.2014	17:37	75°47.34 N	27°35.94 E	1:01	3.47	1.07	244.13	RH	0
5*	17.11.2014	20:08	75°44.05 N	27°13.52 E	1:31	3.54	1.11	217.45	RH	0
6*	18.11.2014	00:04	75°48.48 N	27°27.14 E	1:01	3.46	1.06	240.76	RH	0
7	18.11.2014	01:59	75°50.48 N	27°42.26 E	1:31	3.51	1.03	241.34	RH	0

8	18.11.2014	04:24	75°47.59 N	27°30.82 E	1:30	3.43	1.03	243.28	RH	0
10*	**18.11.2014**	**14:53**	**75°48.23 N**	**31°03.11 E**	**1:03**				**RH**	**1**
12	**18.11.2014**	**22:40**	**75°41.18 N**	**34°14.03 E**	**1:00**	**3.46**	**0.72**	**197.48**	**RH**	**8**
13	**19.11.2014**	**01:29**	**75°40.78 N**	**35°01.43 E**	**0:41**	**3.34**	**0.98**	**168.07**	**RH**	**2**
14	**19.11.2014**	**02:52**	**75°42.50 N**	**35°18.78 E**	**1:34**	**3.39**	**0.92**	**167.90**	**RH**	**11**
15	**19.11.2014**	**04:59**	**75°45.91 N**	**35°43.51 E**	**1:24**	**3.42**	**0.59**	**178.49**	**RH**	**13**
17*	**19.11.2014**	**13:31**	**75°56.17 N**	**37°47.05 E**	**0:40**	**3.42**	**0.22**	**220.18**	**RH**	**16**
18	**19.11.2014**	**16:05**	**75°57.62 N**	**37°36.41 E**	**0:35**	**3.46**	**0.24**	**224.43**	**RH**	**16**
19	**19.11.2014**	**22:14**	**75°58.53 N**	**37°45.77 E**	**0:17**	**3.55**	**0.20**	**235.38**	**RH**	**7**
20	**20.11.2014**	**03:29**	**75°59.98 N**	**37°41.02 E**	**0:32**	**3.44**	**0.18**	**229.95**	**RH**	**9**
21	**20.11.2014**	**07:52**	**75°56.45 N**	**37°31.57 E**	**0:57**	**3.51**	**0.29**	**225.00**	**RH**	**26**
22	**20.11.2014**	**09:53**	**75°57.69 N**	**37°09.75 E**	**1:42**	**3.45**	**0.34**	**226.25**	**RH**	**10**
23	**20.11.2014**	**12:59**	**75°55.02 N**	**37°34.66 E**	**1:01**	**3.30**	**0.44**	**221.90**	**RH**	**29**
24	**20.11.2014**	**15:17**	**75°54.08 N**	**37°14.95 E**	**0:53**	**3.41**	**0.40**	**205.22**	**RH**	**17**
26	**21.11.2014**	**02:12**	**75°35.44 N**	**33°33.33 E**	**1:32**	**3.34**		**238.32**	**SCSG**	**17**
27	21.11.2014	06:29	75°21.92 N	32°33.54 E	1:04	3.33	0.71	279.45	SCSG	0
28	**21.11.2014**	**09:17**	**75°17.09 N**	**32°19.39 E**	**0:55**	**3.23**	**0.70**	**294.36**	**SCSG**	**2**
29	21.11.2014	11:17	75°12.86 N	32°15.56 E	1:32	3.42	0.87	293.98	SCSG	0
30	**21.11.2014**	**13:54**	**75°07.36 N**	**32°08.66 E**	**1:20**	**3.04**	**0.26**	**249.31**	**SCSG**	**1**
31	**21.11.2014**	**16:08**	**75°02.49 N**	**32°08.22 E**	**1:17**	**3.00**	**0.21**	**251.41**	**SCSG**	**1**
32	21.11.2014	18:23	74°59.06 N	31°49.48 E	1:34	3.09	1.00	283.46	SCSG	0
33	21.11.2014	21:04	74°55.40 N	31°32.07 E	1:28	3.14	0.88	319.54	SCSG	0
34	**22.11.2014**	**00:02**	**74°53.82 N**	**31°22.89 E**	**1:36**	**3.45**	**0.87**	**305.08**	**SCSG**	**1**
35	22.11.2014	06:17	74°58.93 N	31°45.49 E	0:50	3.03	0.94	287.88	SCSG	0
36	22.11.2014	11:59	74°58.80 N	31°49.95 E	0:52				SCSG	0
37*	22.11.2014	15:20	74°57.65 N	31°43.08 E	1:19	2.99	0.34	291.85	SCSG	0
38*	22.11.2014	18:44	74°55.35 N	31°28.23 E	1:26	3.21	-0.06	326.15	SCSG	0
41	23.11.2014	04:30	74°58.62 N	31°45.47 E	0:40	3.48	-0.23	289.01	SCSG	0
42	23.11.2014	15:20	75°00.82 N	31°45.85 E	0:19	2.93	0.16	304.75	SCSG	0
43*	23.11.2014	18:52	74°58.97 N	31°37.38 E	1:07	3.20	0.18	306.55	SCSG	0
44	23.11.2014	21:42	75°02.13 N	31°43.88 E	0:28	3.31	-0.07	315.20	SCSG	0
45	24.11.2014	01:19	75°02.32 N	31°44.69 E	0:16	3.37	-0.03	310.99	SCSG	0
46	24.11.2014	09:42	74°43.12 N	30°58.12 E	0:44	3.46	-0.01	315.45	SCSG	0
47*	24.11.2014	12:42	74°41.19 N	31°44.76 E	0:52				SCSG	0

* Hauls where video was recorded and artificial light was used. Bold indicates catches with crabs present.

RH – conventional rock-hopper gear, SCSG – semi-circular spreading gear

3.2 Data Sampled

A total of 187 snow crabs were collected between November 18th and November 22nd. From the 18th to the 20th a total of 165 snow crabs were collected using the conventional rock-hopper gear; five snow crabs were located in the codend and 160 crabs were located in the retainer bag. From the 21st to the 22nd a total of 22 snow crabs were collected using the SCSG; one crab was located in codend and 21 were collected in the retainer bag. No crabs were collected in the two sets of pots deployed on the west coast of Svalbard. The simultaneous cod and haddock escapement study as well as ice conditions were determining factors about where sampling could take place. Packed drift ice encountered during sampling caused the R/V *Helmer Hanssen* to move south away from where snow crab catches had been taking place.

Once the trawling gear was onboard, caution was taken to remove snow crabs from both the codend and retainer bag, keeping the crabs in heavy-duty orange fish/shrimp bushel baskets respective of which net they were collected in, before the remaining catch was put into the ships holds to be sorted, measured and processed. The orange bushel baskets were then placed below deck out of the elements[13] into larger rubber tubs with circulating ocean water, and a covering over the top to prevent escapement while the fish catch was processed. This was done in an attempt to prevent handling damage, however a few smaller crabs were occasionally discovered while sorting the fish catch, they were promptly removed and placed into the proper basket according to net location.

Snow crabs were sexed, as determined by abdomen shape; individually weighed to the nearest gram using the ship's onboard wet lab scale; carapace width was taken to the closest mm at the broadest point using calipers; and individuals were assessed for injury[14]. Data was recorded on waterproof A4 paper, this included date, haul number, and station number according to footgear type and net location (Figure 15, Appendices A).

[13] Temperature below deck was only slight above outside air temperature due to the opening and closing of the holds while fish were being processed.
[14] Soft-shell crab status was also listed on the data sheet to be collected however, did not all crews record when soft crabs were encountered, and is therefore not discussed here.

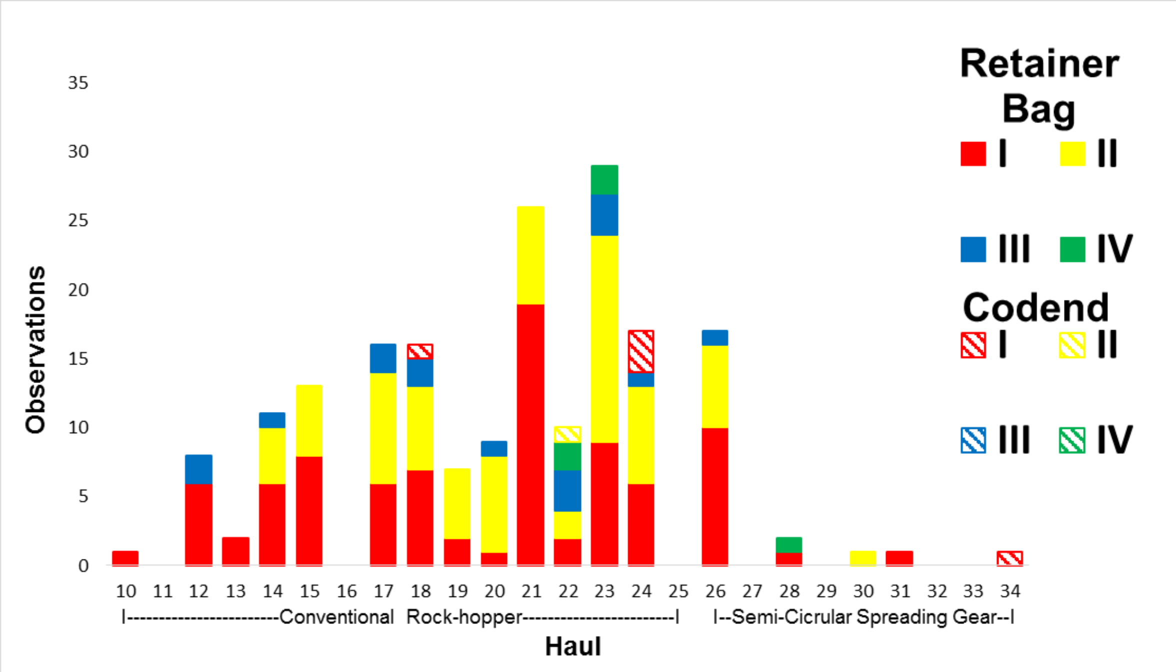


Figure 15. Injury type by haul, groundrope type and net location. No damage/autotomized leg (I), leg damage (II), carapace damage (III) and abdomen damage (IV).

Additional trawl details were also collected from the ship's stasjonslapper (station log) and the Scanmar recording device, these include, start and stop time (UTC), start and stop latitude and longitude, ship speed (knots), bottom temperature (°C), and depth (m) (Table 7) as well as towing direction, wind direction and speed, air temperature and dew point.

SYSTAT® binary logistic regression first removed maximum depth (*p*-value = 0.937) indicating that it did not have a significant effect on whether crabs were injured. Re-running the regression excluding the most insignificant variable then eliminated filmed (*p*-value = 0.639), followed by average depth (*p*-value = 0.509), duration (*p*-value = 0.400), bag type; codend or retainer, (*p*-value = 0.428), groundrope type; conventional rock-hopper or SCSG, (*p*-value = 0.252), speed (*p*-value = 0.205) and average bottom temperature (*p*-value = 0.050). Remaining significant variable included; weight (*p*-value = 0.00), carapace width (*p*-value = 0.01) and sex; however, sex had a *p*-value of 0.046, which could be rounded up to 0.050 although the odds ratio for sex has a lower 95% confidence interval of 1.009 and an upper 95% confidence interval of 2.552, meaning the value is considered statistically significant because it doesn't include the value of 1. With this outcome, the null hypothesis that there is not a connection between variables and injury is rejected, and the alternative that there is a connection, between weight, cw and sex, on the presence of an injury is accepted (Appendices B-D).

3.3 Underwater camera

Video was recorded in nine of the 47 hauls; of these, snow crabs were present in the catches of only two of these tows. Problems with the camera set up and performance resulted in a limited amount of video footage to analyze; of the two videos, poor camera angles and the lighting system used caused deficient lighting/shadows in the front of the groundrope limiting the quantity of video footage even further. Recordings from the low light camera provided low quality video results that after several trials it was no longer used. A total of 02:42:06 (hh:mm:ss) of video footage was viable, of which 00:00:45 entailed verifiable encounters with snow crabs. Within the frame of the video, visibility in front of the net was often limited to a very short distance; even with video slowed down, it is nearly impossible to distinguish what is passing by before it is overtaken by the net (Figure 16). Distance from the camera to the trawl also caused issues with lighting, either making the frame dark and indistinguishable or creating a focused beam of light that darkened the majority of the trawl area and again limiting the frame to a short distance in front of the ground gear.

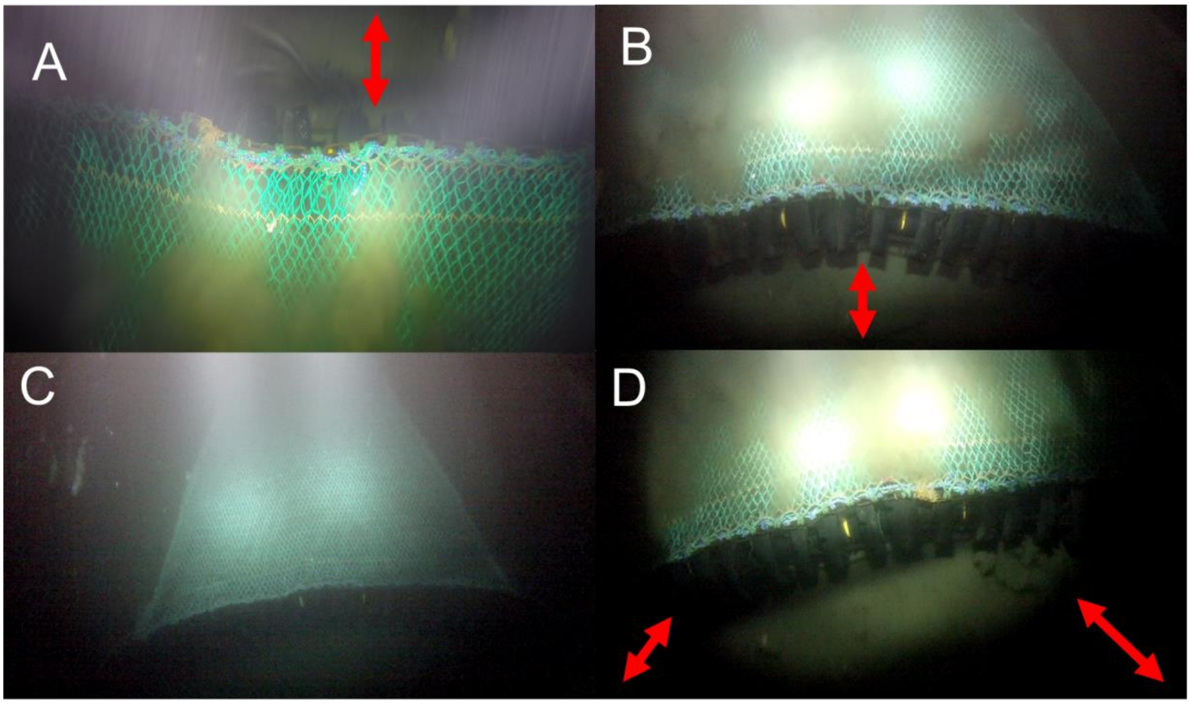


Figure 16. Examples of problematic footage from video; limited distance in front of the trawl (A and B), increased distance from camera to trawl caused darkness (C) and focused beams of light that excluded the majority of the trawl area (D).

3.3.1 Behaviour

With the image quality and quantity issues mentioned above, it was often difficult to distinguish between snow crabs and other benthic organisms with similar coloration (i.e. sea stars) especially if they were partially buried in the sediments. Of the 00:00:45, a total of 21 snow crabs were verified, the majority of the encounters were one minute or less in duration, with the longest encounter lasting 00:00:17 when a snow crab was “kicked-up” and was then dragged along the bottom underneath the disc. Successful video footage provided limited insight on behaviour, although some crabs did appear to be at least partially buried prior to the direct encounter with the trawl in some of the videos, with only a portion of the head, carapace and or legs visible (Figure 17). It is possible that these crabs were in the process of reacting to the impending trawl just prior to coming into the camera frame, which was often times limited to a very short distance in front of the trawl, presumably reacting to the impending trawl. Eighteen of the crabs appeared to be at least partially buried when they came into focus of the camera, with the remaining three on the surface. Two of the crabs, one partially buried and one on the surface, were facing the trawl prior to the encounter (Figure 18), while the third surface crab was along with the majority of the buried/partially buried crabs were positioned perpendicular to the oncoming gear. A few appeared to be moving away from the trawl before they were quickly overtaken, however as mentioned before a majority of the encounters were less than a minute coupled with the limited frame of view provided by the camera positions. This speculation is based on the amount of surface that was visible, possibly indicating movement had just recently occurred or was in the process of unburying itself in an attempt to escape. During the study conducted by Nguyen et al. (2014) they assumed that crabs perceive an approaching bottom trawl in the same way that fish perceive an approaching bottom trawl, and in this assumption were able to build upon established predator – prey theory for animal – trawl interactions as has been discussed by Ryer (2008) and Winger et al. (2010).

Figure 17. Video footage showing snow crab mostly buried while being overtaken by the groundrope.

Figure 18. Sequence of a snow crab interacting with the trawl net.

No formal data analysis was able to be conducted due to the poor video quality and the limited number of snow crab/trawl interactions caught on video (n = 21). Nguyen et al. (2014) found that the crabs that did encounter the footgear, 95% went under while 5% went over. Comparably, in this study overall 97% of the snow crabs went under the groundrope and were found in the retainer bag while 3% of the snow crabs went over and were found in the codend. The however was not represented by the video in which 100% went under the trawl.

4.0 Discussion

In the Nguyen et al. (2014) study, the area used for the experiment was selected because there is known overlap between the shrimp and snow crab fisheries and it had been recently closed due to high incidence (>20%) of soft-shelled crab. This ensured the absence of crab gear and allowed trawling to occur without gear conflict; it also meant that soft-shelled crabs were present in the area. In the Barents Sea, there is overlap between not only the shrimp and crab fishery but also the cod and haddock fisheries, however, because of the location of this still developing fishery, regulations limiting gear or area closures when soft-shelled crabs are present do not exist. In addition, the field observations in the Newfoundland study took place in late June, which removes the threat of encountering seasonal ice. The presence of ice in and around the main fishing ground in November not only limited the ability to trawl, but also eliminated the ability to set out pots to verify crabs were present in the study area. While certainly not all, many studies performed on snow crab also take place during summer months; June and July (Stoner et al., 2008) and August for both (Hammond et al., 2013, Rose et al., 2013) seemingly after the close of the season or fishing area, not only reducing conflict but also unfavorable weather conditions.

The trawl in this study was set up in a semi-pelagic configuration unlike the bottom configuration used among the majority of fishing fleet in the area. While the focus for this study was on the center section of the trawl, for both video and collection of snow crab, the overall outcome could be biased and not give an accurate picture of the interaction between snow crab and trawling gear in the Barents Sea. As Rose (1999) points out, the largest portion of the area swept by most bottom trawls is covered by the sweeps, which connect the trawl net to the trawl doors. Stoner et al. (2008) used recapture nets (small 2-seam trawls) set up with headropes longer than the footropes to maximize the escapement of fish and small diameter (50.0 mm) footropes to enhance crab capture. As a control for damage in the recapture nets, they fished the recapture nets ahead of the main trawl, capturing crabs with no previous damage, limiting tow times to approximately 15 minutes. The set-up allowed for capture from various locations around the trawl, in order to test that crabs had experienced stressors typical of those produced during encounters with fishing gear, not limiting capture to the center section. Nguyen et al. (2014) used a traditional shrimp trawl with a 40.0 mm mesh size, compared with the 135.0 mm mesh sized used for this study. While mesh size was not tested in this experiment, consideration can be made that the increased mesh size poses and increased risk of injury to crabs by getting their legs caught, however a study would need to be conducted to verify this speculation.

The set-up of both the camera and lighting units caused problems when it came time to observe snow crab interactions with the footgear. A similar low light camera to the one used in Nguyen et al. (2014) provided no viewable footage of the area in front of the groundrope. Field-testing of camera and lighting unit placement could have allowed for adjustments to be made prior to data collection, increasing the field of view and making sure lighting was adequate for post-trial review and analysis.

In the established fisheries, regulations on season and area closures do a lot to mitigate conflict between multiple user groups. For example, in Canada, a large proportion of the fleet participates in both the shrimp and snow crab fishery, the offshore shrimp fishery takes place year round, while the inshore fishery takes place spring – fall/season closure due to soft-shelled crabs (DFO, 2015d). Fishers usually participate in the more profitable snow crab fishery and switch over to shrimp trawling when the crab season close, thus reducing conflict.

In the Barents Sea, there is already a conflict between bottom trawling (fish and shrimps) and crab potting, especially in the Loophole area with high concentration of pots (Fenstad, 2015a). Trawlers report on catches of hundreds of lost pots (due to drift-ice moving pot strings and breaking buoy lines) and crab vessels claim that trawlers do not respect the reported positions on pot-fleets. Norwegian authorities have been contacted about ghost pots in the Loophole, however they are unable to intervene, and with no authority nobody wants to take responsibility (Fenstad, 2015a). So far, there are no reports of pot conflict in the Svalbard Zone; however, with limited space in the Loophole and Russian claim to the continental shelf, limiting who is allowed to put pots there, that could soon change (Fenstad, 2015b, Fenstad, 2015a). There is anecdotal talk from the Barents Sea fishermen, that the pots they are pulling up in their trawls are, "filled to the top with snow crab." In both the U. S. and in the province of Newfoundland and Labrador, the use of a degradable excluder device on crab pots is a mandatory condition of the license (DFO, 2015a, NOAA, 2015b). According to Fenstad (2015a) there are a few potters in the Barents Sea that use degradable twine, but it is not a common occurrence.

4.1 Injury

It is recognized that damage to the crab could have occurred either prior to the trawl by a recent encounter with a predatory species, during interaction with the groundrope and or within either the codend or the collection bag. Previous autotomization showed signs of healing/calcification and thus were categorized the same as if no damage had occurred during the trawl. Video footage was inconclusive and did not allow for comparison between crab encountering the two different groundropes and the injuries of crab harvested in the collection bag or the codend of the trawl.

The number of snow crabs collected during this experiment is a limiting factor when it comes to determining factors that cause injury. Using the catches from the retainer bag for the rock-hopper gear and a simple power of analysis indicates a sample size of at least n = 500 would be necessary due to the high variance in data.

Soft-shelled crabs were not looked at as a category here, but as Nguyen et al. (2014) pointed out, soft-shelled individuals would be unable to respond to an approaching trawl and therefore would be more susceptive to mortality and damage.

4.2 Effects of artificial light

It is well known that artificial light is known to alter animal behaviour and there are numerous studies that have shown the reactions of fish towards fishing gear is altered when external light is present (Engås et al., 1998, Glass and Wardle, 1989, Olla et al., 2000, Walsh and Hickey, 1993). However, in a study conducted by Miller (1975) it was reported that the use of a strobe flash for underwater photography did not cause snow crabs to move away from where they were partly buried. In addition, during a study conducted by Watanabe (2002) a deep-sea video monitoring system was places on a towed sledge in order to estimate the population density of snow crabs. The field of view was in front of the sledge and there was indication that the light did little to effect the snow crabs behaviour, and that crabs that did move likely did so as a reaction to the approaching towed sledge. While there were observations of snow crabs seemingly in motion prior to coming into view of the camera, as mentioned before, there was not enough video footage collected during this experiment to draw any significant conclusions. Moreover, while it cannot be certain that the artificial light had little to no effect on the crabs, it is a recognized limitation that the depths at which snow crabs are located as well as the seasonal absence of light requires the use of artificial light in order to collect video footage.

4.3 Economics of the snow crab industry

Global markets consume about 1.5 million tonnes of crab (all species) annually. In recent years, snow crab has accounted for about 10% of the total supply (150,000 tonnes), with Canada as the leading producer (55-60%) (Gardner, 2014).

The price for snow crab is variable dependent on an number of factors some of which include, size, quality and availability of the crab, suitable alternatives/substitutes, limited markets and global exchange rates (Gardner, 2014). Damage to crab, such as those resulting from encounters with the mobile gear sector, will therefore affect the overall price.
Currently, Norwegian fishers are being paid approximately $2.00 USD/kg for live snow crab, while (at sea) frozen legs are paid approximately $7.25 USD/kg (Anonymous, 2015).

4.4 Recommendations for future

To better understand how trawling is affecting snow crab, additional under water observations of interactions between crabs and other trawl components (doors/sweeps) should be studied. Pre-trial testing of camera and lighting equipment should be performed in order to ensure placement of equipment is such, that the field of view allows for usable video. When the study is performed it is also an important to note, late season trials in the Barents Sea increase the likelihood the study area will be affected by sea ice and rough weather, this not only can reduce the study area but it can also affect the performance of the trawl, especially if it is in a semi-pelagic set-up. As was seen in this study, the sea-ice caused the study area to move enough away from where crabs were located that ultimately, the sample size was affected.

Additional study recommendations would include, comparing injury results to the different mesh sizes used in the area (i.e. 40 mm shrimp fishery 130 mm cod fishery). Looking at trawl modifications in order to reduce bottom contact such as groundrope set-ups designed for crab/other benthic species avoidance. This study was conducted in a semi-pelagic set up which, according to Rose et al. (2013) can help to reduce unobserved mortality of king crab from 10% to 4%. Evaluating biodegradable twines for use in the Barents Sea pot fishery in order to reduce ghost fishing when conflict between gears, user groups, nature and/or jurisdictions arise.

Several management measures are in place for the sustainable management of *Chionoecetes* spp. In the Bering Sea, area closures and bycatch limits for the groundfish trawl fisheries, and an assumed fixed rate of mortality for discarded crab in both the targeted pot fisheries (20% for Tanner crab and 50% for snow crab) and non-targeted bycatch in the groundfish trawl fisheries (80% for snow crab) (Hammond et al., 2013, Siddeek, 2003).

4.4.1 Management recommendation

As the Barents Sea has many similarities to waters off Newfoundland and Labrador, it would be to the advantage of Norwegian and Russian authorities to use the lessons learned in the Canadian snow crab fishery, as a building block when developing regulations and management practices in the area.

Because of the remote location of the fishing grounds, cost-to-access (fuel prices, price for catch) as well as variable weather conditions likely limits some access/effort to the area for all gear types. Licensing requirements could be extended to include VMS systems and dockside monitoring, which could help for quota management purposes, should quotas be issued to individual vessels.

While area/season/gear restrictions would be difficult to enforce in the Strategic Conservation Frameworks for Atlantic Snow Crab report (2005) industry representation during public consultations focused on the fact that grid closures to protect soft-shelled crab are ineffective if fisheries that use bottom contact gear, such as for groundfish and shrimp are allowed to take place. There is concern among the industry in Canada that the mobile gear sector represents an important source of unaccountable mortality, negatively affecting the snow crab population and/or habitat (Nguyen et al., 2014). An additional source of snow crab mortality comes by way of ghost fishing; therefore it should be seriously considered to require all potted gear to possess a biodegradable excluder device. Gear restrictions should not be limited to the pot fishery, as it has been shown by Rose et al. (2013), raising the sweeps can help to reduce unobserved damage and mortality, which could be particularly important in times when snow crabs are known to be molting. In addition to gear restriction, a cooperative agreement between participating member nations should be discussed/considered, for the pick-up and removal of ghost pots and other derelict fishing gear in areas of no authority. Ghost fishing is not only a costly problem for potters who lose their gear and trawlers who nets can be ruined by capturing pots, but it also poses as threat to wildlife.

Russian vessels are currently restricted to a 100 mm minimum size limit that is most likely due to the already established size limits of the snow crab fishery in the east. As of yet, Norway does not have an established size limit, however, most fishers are using conical traps, typical of those used in the Canadian snow crab fishery designed with a selectivity of 95 mm. Establishing a single size limit for harvest of snow crabs in the area of the Loophole and Svalbard Zone is most likely not necessary. As is seen in the US, where they have a smallest minimum size limit, 78 mm cw, processors are requiring crabs to be of a higher minimum size than is required by local authority, effectively eliminating the need for size limit that is currently in place (ADF&G, 2015, NOAA, 2015b, NOAA, 2015a, Otto, 1989).

5.0 Summary and Conclusions

Although there are many obvious limitations in this study, more work should be done collecting data in order to get a better understating of the interactions that take place between snow crab and the mobile gear sector in the Barents Sea.

The November trawl study performed in the Barents Sea suggests that a majority of snow crabs are able to escape underneath the groundrope and avoid capture in the trawl fishery. However, which variable(s) influence injury as a result of an encounter was unable to be determined, nor was the behaviour of snow crab encountering mobile gear.

As more boats enter into the snow crab fishery, the potential for conflict between not only snow crab and trawlers increases but also the conflict between trawlers and potters over space. This is especially true given the recent action of Russia taking control over much of the Loophole without notifying Norway (Fenstad, 2015c). Loosing access to fishing in the Loophole further condenses the already cramped Barents Sea fishery.

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Appendices

Appendix A. Example of Datasheet used in November trawl study in the Barents Sea.

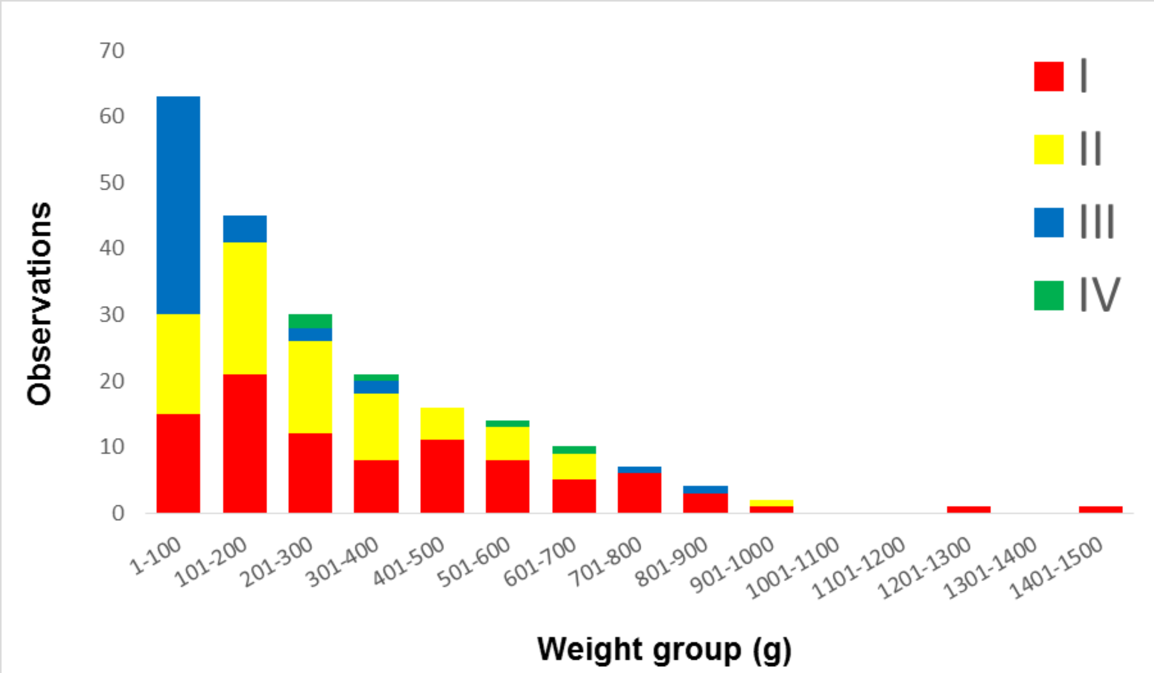
Haul #: **Station #:** Codend ☐

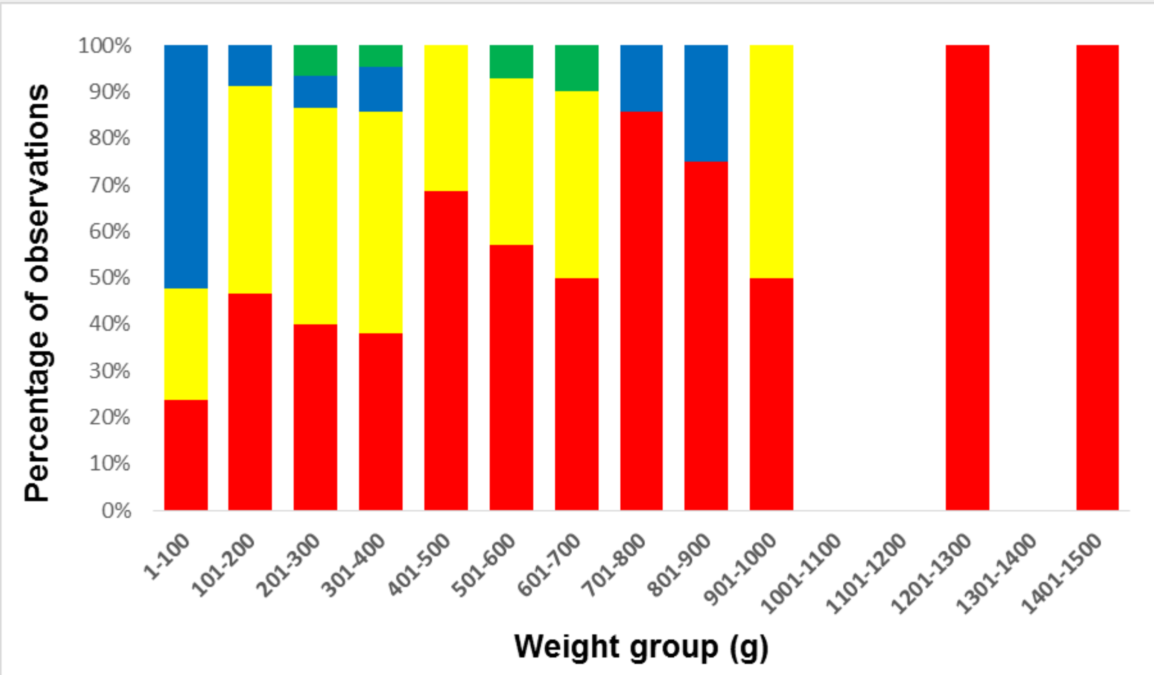
Date: Retainer Bag ☐

Footgear type Rockhopper groundrope ☐ SCSG groundrope ☐

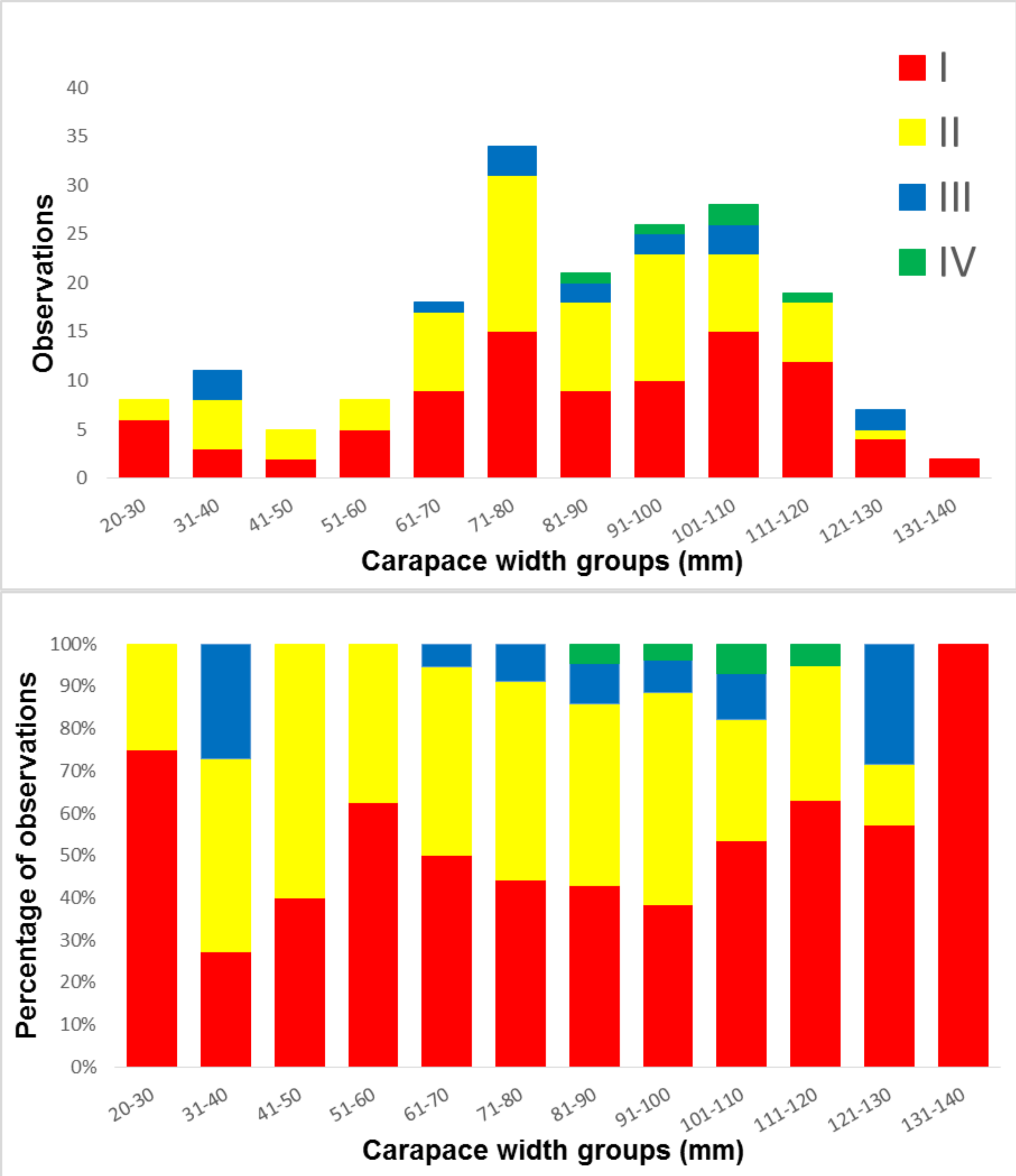
Status I-Autotomized Leg/No Damage; **Status II**-Leg Damage; **Status III**-Carapace Damage;
Status IV-Abdomen Damage ***If multiple injuries, categorize under the most serious*** **S**-Soft

CW (mm)	Weight (g)	Sex (M,F,U)	Status (I,II,III,IV /S)	CW (mm)	Weight (g)	Sex (M,F,U)	Status (I,II,III,IV /S)

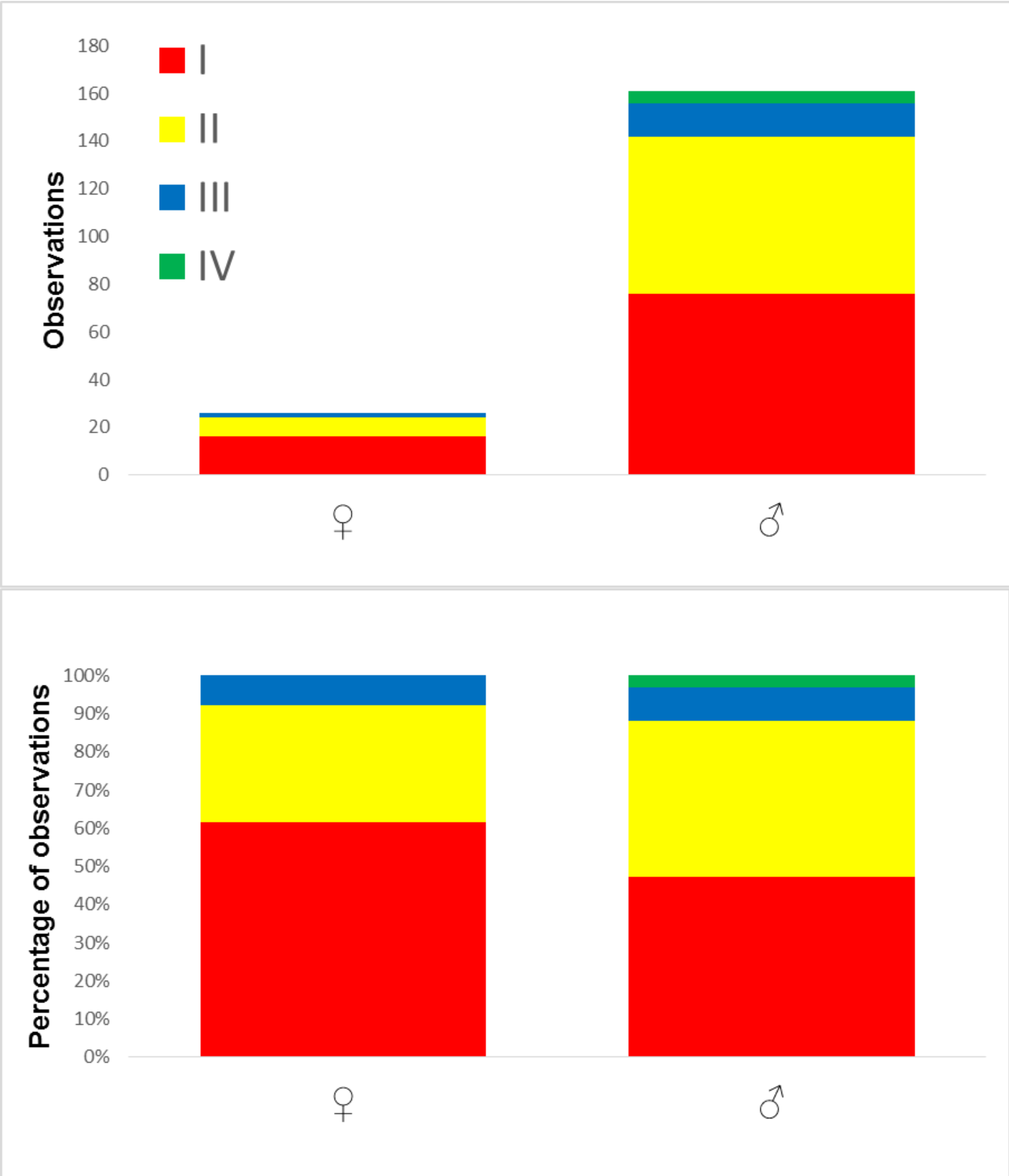




Appendix B. Injuries by weight group (g).



Appendix C. Injuries by carapace width groups (mm)



Appendix D. Injuries by sex.